HIGHWAY RESEARCH REPORT

STRUCTURE BACKFILL TESTING

FINAL REPORT

STATE OF CALIFORNIA BUSINESS AND TRANSPORTATION AGENCY DEPARTMENT OF TRANSPORTATION DIVISION OF HIGHWAYS	TRANSPORTATION LABORATORY RESEARCH REPORT CA-DOT-TL-2130-1-73-41

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration November, 1973

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This study was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration. Study title: Structure Backfill Testing.

16. ABSTRACT

This study was performed because of concern that the nuclear gage did not measure the density of structure backfill accurately due to the effect of concrete walls or pipes.

Field and laboratory studies indicated that the gage is able to give a good estimate of the inplace density and that wall effect is not significant if the test is properly performed. Field correlation tests between sand volume and nuclear methods indicated the sand volume tended to give slightly higher test results. Laboratory research also indicated the sand volume tends to measure above the true density when the density of the material is above 120 pcf.

Comparison of sand volume data from the pre-nuclear era and the present nuclear tests indicated that more passing tests were obtained with the sand volume test. This was believed due to inaccuracies of the sand volume test.

This study indicated the relative compaction specification of 95 percent should be retained.

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STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
TRANSPORTATION LABORATORY
5900 FOLSOM BLVD., SACRAMENTO 95819

November 1973

Trans. Lab. No. 632130
Fed. No. F-4-37

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is the final research report titled:

STRUCTURE BACKFILL TESTING

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Principal Investigator

Under Supervision of
Raymond A. Forsyth, P.E.

Very truly yours,

JOHN L. BEATON
Chief, Transportation Laboratory

ACKNOWLEDGEMENT

Credit for this study should be shared with Bobby Lister and Pat Monahan of the Transportation Laboratory. Their conscientious effort in the field and laboratory contributed substantially to this project.

The authors also wish to express their appreciation to the Construction Departments of Districts 02, 05, 08, 10 and 11 for their cooperation. Particular recognition is extended to the Resident Engineers and their staffs on the various projects where the field research was performed.

The research work reported herein was accomplished under the Highway Planning and Research Project F-4-37 in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

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INTRODUCTION

This study was undertaken because of a concern that the nuclear gage did not accurately measure the density of structure backfill. Field personnel indicated more failing tests using nuclear gages than by conventional sand volume methods. Many field and research personnel suspected that nuclear density tests were affected by the proximity of concrete wall and pipe.

The researchers believed the problem should be classified into the following broad, general areas:

1. Under test methods 231E and 911A dated April 5, 1971, the calibration of the nuclear gages is based on standard concrete and natural stone blocks.[1] This calibration system is based on two California Division of Highways studies in which correlations were made between mold densities and the standard blocks.[2,3] The Department of Transportation recognizes that the nuclear procedure based on standard blocks[1] may not give comparable results with the sand volume test[4] in all cases.

2. Earlier test methods did not clearly define the proper procedure when testing structure backfill material with the nuclear gage. Various testing modes, positioning of the detector next to the concrete wall and confining areas in some cases resulted in lowered nuclear test densities. Even after a clearly defined method had been issued, it was difficult to change the bias of many field personnel that the nuclear gage results were affected by the proximity of structures. A study previously performed on this subject is attached to this report as Appendix A. The present test procedure states that the source detector axis must be at least 8 inches away from any obstructions.

A research report was published indicating the effect of concrete walls on moisture measurements.[5] In some cases, the results of this study were being mistakenly extended by some field personnel to include density measurements next to walls.

3. Before nuclear testing was adopted, there were many cases where structure backfill could not be tested with the sand volume test due to the granular nature of the material (ie, pea gravel and some sands). The sides of the excavation for the sand volume determination would cave in thereby precluding any testing. In these cases, the contractor operations were controlled by a maximum 8 inch lift and visual inspection of the compaction. There was no way to determine if the compaction requirements were being met.

4. In some cases, excessive moisture and/or a cohesionless type material caused the sand volume test hole to shrink or the cone to settle in the material being tested. Kneeling next to the hole during excavation or standing next to the hole while pouring the sand also caused hole contraction. An erroneous increase in density would be recorded in these cases. Working with a nominal hole volume of 0.15 cubic foot and density around 130 pcf, a change in hole volume of 0.001 cubic foot can cause a change in density of around 0.8 pcf.

5. Reports authored by Smith[5] and Kerston and Skok[6] have reported that the sand volume test tends to give as much as 8 pcf higher densities than the actual density of the material being measured. Granular type materials appear to be affected most.

Nuclear testing was officially adopted as a standard test by the California Division of Highways in November, 1966. The nuclear gages were calibrated to sand volume results at that time. This was an arbitrary procedure where judgement was used to suit job conditions. In April 1971, the gage calibrations were based on standard blocks. Therefore, the basic comparison being made is between the sand volume and current nuclear method when testing next to structures. Because of its variable nature, an attempt was made to normalize the data wherever feasible. The work was not always carried out as planned due to contractors operations, job conditions and availability of equipment and personnel.

OBJECTIVES

1. Perform studies under laboratory conditions comparing sand volume and nuclear testing in structure backfill material next to concrete blocks.

2. Perform similar studies under field conditions comparing sand volume and nuclear testing in backfill material.

3. Determine if there is a wall effect and a resultant lowering of the measured density when testing structure backfill with the nuclear gage.

4. Determine if a lowering of the relative compaction specification for structure backfill is necessary or desirable.

CONCLUSIONS

1. Under laboratory conditions, this study indicated that the nuclear gage calibrated to standard blocks can satisfactorily be used to determined the density of a material compacted in a 2.25 cubic foot mold. The same is true for the sand volume test for densities to approximately 120 pcf. However, the sand volume indicates about 2 to 3 pounds above the mold value when the density is above 120 pcf.

2. Eighty-two comparisons in structure backfill material from 5 ongoing construction projects were made between the sand volume and nuclear methods. The nuclear gage was calibrated to standard blocks. The average for all 5 projects indicated the sand volume method averaged 1 1/2 pcf higher density. However, three of the five projects showed about the same average densities for the two methods.

3. Test results with the nuclear gage calibrated to sand volume show the least percent failing tests (28.1%) on a statewide average. The sand volume is next (30.8%) and the nuclear calibrated to standard blocks show the greatest percent failing tests (38.2%).

Suprisingly, however, in one district where sufficient data was available, the sand volume showed about 5 percent more failing tests than the nuclear gage calibrated on blocks.

4. Field and laboratory studies showed no discernable wall effect if the test was performed according to procedure. This is supported by some limited data from a previous project.

RECOMMENDATIONS

A limited survey of structure approaches during this study indicated there continues to be a settlement problem. The results of this and other studies influenced the researchers to recommend the current specification of 95 percent relative compaction be retained for compaction of structure backfill.

BENEFITS

This research should reestablish confidence in testing of structure backfill material with the nuclear gage.

Some direct cost savings should result from minimizing retests due to failing tests. Potential contractors claims should also be minimized.

During the initial phases of this study when there was concern that the nuclear gage was not giving accurate test results, there was some thought given to lowering the compaction specifications. If this research had not been performed and the specification was lowered, there would generally be an increase in the settlement of structure backfill material resulting in increased maintenance costs of restoring bridge approaches to profile grade.

The experience and data developed from this research will be used for future training of personnel involved with nuclear gages. The information will also be used in a continuing operational study of compaction control procedures.

IMPLEMENTATION

The results of this study indicated the current procedures are adequate and no modifications are needed in our test methods, Standard Specifications and Construction Manual.

DESCRIPTION OF FIELD PROJECTS

Project M

This project was on State Highway 1 located near the City of Monterey, California and was about one mile from the Pacific Ocean. The structure backfill material tested was a brown sand. Table I shows an average grading analysis for this material and the other structure backfill material from projects described below.

Project W

This project was on Interstate 5 located in Northern California near the town of Weed. The structure backfill material job was a granular, lightweight, graded volcanic material.

Project T

This project was on State Highway 99 near the town of Turlock in Central California. The structure backfill material tested was a silty sand.

Project N

This project was on Interstate 40 near the town of Needles in Southern California in the desert. The structure backfill material tested consisted of silty sand and some rock.

Project S

This project was located on Interstate 5 between the Mexican Border and San Diego, California. The structure backfill material was silty sand.

TABLE I

Summary of Gradings of Structure Backfill Material

Sieve Size	Standard Specs Jan 71 % Passing	Project M % Passing	Project W % Passing	Project T % Passing	Project N % Passing	Project S % Passing
3"	100	100	100		100	100
#4	35-100	98	85	100	92	98
#30	20-100	77	65	94	46	62
#200	None	10	29	23	23	15

These tests represent the average of three gradings.

DISCUSSION

Sand Volume and Nuclear Testing in the Laboratory

The laboratory study consisted of carefully compacting soil in a 2.25 cubic foot mold having removable sides. The compacted material in the mold was used as a standard for comparison purposes even though some variation in density was exhibited. The sand volume apparatus and the nuclear gages calibrated to standard blocks were used to measure the density of the material in the mold. Structure backfill material from ongoing construction projects was used. An estimate of the accuracy of the two tests could be determined from the deviation of the measured density from the calculated density of the mold. All tests were performed on the side of the mold perpendicular to the layers of compaction. This minimized any density gradient in the mold and also provided a very smooth surface upon which to perform the test.

Figure 1 shows a plot between mold and nuclear gage densities of structure backfill and other materials. In general, there is excellent correlation between calculated mold density and gage measurements.

Sand volume tests were performed in the mold after the nuclear test. Figure 2 shows a plot of this data. Data from other tests on various materials increased the total number of tests to 120. The sand volume densities on material above 120 pcf were found to be about 2 to 3 pcf higher than the mold densities.

Research by Kerston and Skok[6] confirms this lack of correlation. The paper by Redus[7] using another approach also indicates the sand volume test reads high for certain materials. Redus's reason for the higher sand volume densities is bridging of the sand over void pockets when testing granular material. A discussion on Redus's paper by J. R. Sallberg, Research Engineer of FHWA stated that studies performed by FHWA indicated sand volume tests averaged +7 pcf higher for sand volume over undisturbed densities on granular materials.

Figure 3 shows nuclear tests being performed on material compacted in a metal box 18"x18"x12" deep. The tests were then repeated with 4"x5"x18" concrete blocks stacked next to the mold and gage. Table II shows a tabulation of the test data. This laboratory procedure was used to determine if the gage readings were being affected by the proximity of the concrete blocks. There appeared to be no significant effect from the concrete blocks for all material tested. There was some tendency for the nuclear tests to measure low and the sand volume tests to measure higher than the mold value. In some cases where the material was compacted 2 to 3 percent over optimum, there was a noticeable squeezing of the hole resulting in high densities.

Sand Volume and Nuclear Testing in the Field

Figure 4 shows how adjacent material was changed as field tests were performed on structure backfill material. A nuclear test was performed in an area away from all obstructions. After the initial test, a hole 12"x15"x24" was excavated next to the gage and a second test was performed. The third and fourth tests were performed with 4"x5"x18" concrete beams stacked in the hole and, finally, a 1/4 inch steel plate was placed next to the gage. Table III shows a tabulation of the test data. The test data indicates no significant wall effect on gage readings under these conditions.

Figure 5 shows sand volume and nuclear tests performed at various distances from concrete walls and pipes. Table IV shows a tabulation of the data. No significant wall or pipe effect could be detected.

The following Table V presents a summary tabulation of the comparison between field sand volume test results and those with nuclear gages calibrated on standard blocks. These tests were performed on structure backfill.

TABLE V

Summary Comparison of Field Nuclear and Sand Volume Tests

Project	Type of Material	N	Average Density pcf		Range of Densities pcf	
			Nuclear	Sand Volume	Nuclear	Sand Volume
M	Sand	18	112.7	116.3	103.4-122.8	110.1-128.0
N	Si,Sd & Rock	13	119.6	118.3	115.8-122.5	115.4-121.9
T	Silty Sand	24	123.9	124.1	116.1-127.7	116.2-132.6
S	Silty Sand	24	123.8	125.5	114.1-134.2	115.5-134.8
W	Graded Volcanic	4	117.1	123.3	111.4-129.0	114.1-135.5
	Average		120.4	121.9		

Figure 6 shows a plot of the above data. The data indicates the sand volume with generally higher densities than the nuclear for low density materials (110-115 pcf) and for the high density materials (128 pcf and higher).

The higher densities obtained by the sand volume method was commented on in the previous section on laboratory tests. The higher sand volume densities for the low density material is believed due to squeezing of the hole. The tester normally kneels next to the hole during excavation and stands next to it while pouring the sand. Cohesionless (some sands or pea gravel) material and wet (over optimum) material are particularly susceptible to squeezing.

Figure 7 is a drawing which shows how nuclear gage tests were performed on structure backfill material next to reinforced concrete pipes. Table VI shows a tabulation of the tests from the various projects. Comparisons were made between sand volume results and those using two types of nuclear gages. The source detector axis was placed parallel to the flow line of the pipe in some cases and perpendicular in others. The average test results indicate no significant differences between gages but generally higher density values for the sand volume tests.

Table VII shows comparative nuclear and sand volume data from two projects. The tests were performed away from all obstructions in generally fine grained backfill material. The average values are about the same for the sand volume and the nuclear test methods.

Comparative Job Test Data Using Different Testing Procedures

Sand volume test data from projects completed in the early 1960's before the nuclear era were compiled. Table VIII shows a tabulation of this data by Districts on a statewide basis. Data were collected from those projects that had sufficient number of tests that were readily available.

Table IX shows the same type tabulation of field data from completed projects that used nuclear gages calibrated to sand volume tests (test method 231D).

Table X shows the same type tabulation from projects that used the nuclear gages calibrated to standard blocks (test method 231E).

A summary of the statewide averages for the three types of testing is shown on the following table XI.

TABLE XI

Summary of Data From Tables VI, VII and VIII

	No. of Projects	No. of Tests	Percent Relative Compaction Average	% of Tests Below 95	94	93	92
Sand Volume	32	3,779	95.6	30.8	24.8	19.3	14.7
Nuclear Calibrated to Sand Volume Method 231D	12	1,959	95.6	28.1	21.2	14.8	11.3
Nuclear Calibrated to Blocks Method 231E	22	3,509	94.6	38.2	28.4	20.5	13.7

The following Table XII shows the same data as above for the sand volume test and the nuclear gage calibrated to blocks for District 04.

TABLE XII

Comparison of Sand Volume and Nuclear Tests From District 04

	No. of Projects	No. of Tests	Percent Relative Compaction $\bar{X}$	% of Tests Below 95	94	93	92
Sand Volume	7	617	94.9	40.4	31.0	25.1	19.0
Nuclear Calibrated to Std. Blocks (231E)	4	283	94.8	35.0	25.1	20.1	14.5

The comparisons here show the sand volume with more cases failing than the nuclear. However, this is not the case on a statewide basis. The reasons for this are not known.

In general, factors which may have contributed to the fewest failures with the sand volume test and the highest percentage of failing tests for the nuclear gages calibrated to blocks are summarized as follows;

1. The hole for sand volume measurements tends to squeeze during excavation and pouring of the sand. This is common when dealing with cohesionless and/or wet materials. Thus, sand volume tests tend to indicate higher densities on granular materials. These items were previously discussed in this report.

2. Resampling is only performed on failing tests. The probability is that a passing test by resampling is improved without additional compactive effort.[8] There is less tendency to resample with the nuclear gage before re-working due to the greater degree of confidence resulting from multiple tests as compared to only one sand volume test.

3. The nuclear gage is used more extensively by the contractor as a job control device to indicate specifications are being met. Control is not as feasible with the sand volume test because it is time consuming and requires the contractor to stop his equipment operation.

4. Part of the data shown on Table X for nuclear gages calibrated to blocks are from ongoing projects. It is believed that the majority of failing tests occur during the initial part of the project with fewer failures as the job progresses. Thus, the actual percentage of failing tests using nuclear gages calibrated by blocks may be less than indicated.

7. Figure 8 shows a nuclear gage calibrated to sand volume tests. The different curves were drawn through the data points by seven independent operators. The extremes between the calibration curves can vary the density readings by as much as 5 pcf. This could reflect what was done on field projects with operators tending to draw calibration curves that result in the highest possible percentage of passing tests. This may indicate why the nuclear gages calibrated to sand volume resulted in more passing tests than the other two procedures.

Discussion of Compaction Specifications

The following Table XIII summarized the specification requirements for structure backfill during the past 25 years.

TABLE XIII

Compaction Specifications for Structure Backfill

California Standard Specifications	Grading		Lift	SE	% Relative Compaction	Test
Prior to 1954	-		4"	-	90	216 (sand volume) 5 layer
August 1954	4" max		8"	30	95	216 (sand volume) 5 & 10 layer
January 1960	2-1/2" #4	90-100 35-100	8"	30	95	216 (sand volume 5 layer
July 1964	3" #4	100 35-100	8"	30	95	216 & 231 Nuclear Calibrated to Sand Volume (November 1966)
January 1971	3" #4 #30	90-100 35-100 20-100	8"	20	95	216 & 231 Nuclear Calibrated to Standard Blocks (April 1971)

A major change took place in 1954 when the specification for structure backfill was raised from 90% to 95% relative compaction and the method of determination of the test maximum density was modified. The 10 layer method was used for all materials placed within 2 feet of finished grade and for those soils with a sand equivalent of 25 or more. Structure backfill met these criterias. These changes represented a major increase in the compaction requirements. In 1960, the 10 layer method was abandoned since the sand equivalent had to be known before a determination of the correct compaction procedure could be made. It was also felt that the requirements were higher than necessary.

In November of 1966, the nuclear gage calibrated to sand volume test data was adopted. The data from Table IX indicates a higher proportion of passing tests for this method. In November 1971, the nuclear calibrated to standard blocks was adopted. The data from Table X indicates that the current procedure has more failing tests than the sand volume method or the nuclear gage method with calibration to sand volume data. However, the current procedure requires less compaction than the 1954 procedure (10 layer).

Compaction of structure backfill to a 95 percent relative compaction is generally a difficult and nonuniform process as compared to material placed in embankment or the structural section. The contractor is not able to use heavy equipment in confined areas. This can result in erratic densities with the average usually meeting specifications. Zeiler and Kleiman[9] reported 16 percent (1,566) of the structures in the California state highway system showed approaches which constituted a maintenance problem. Discussions with the researchers indicated many of the settlement problems could have been related to compaction of the structure backfill. However, no actual breakdown was made of settlement believed due to inadequate compaction.

In 1971, a major freeway was constructed close to the California Department of Transportation Laboratory. Several structure approaches exhibited a definite settlement of the structure backfill. These structures were placed on original ground. Measurements indicated settlements in excess of 2 inches within 2 years after completion of construction. Figure 9 shows photographs of the settlement. Project records indicate all tests met the compaction specification of 95 percent of the California 216 method. Limitations of this study did not permit a more extensive research into this facet of the problem.

Skok[10] indicated in his studies that a settlement of 0.5 inch is to be expected for backfill soils compacted to 95 percent of AASHO T-99. However, settlements of about 1.5 inch can be expected 50 percent of the time if less than 90 percent of AASHO T-99 is attained. Although the AASHO T-99 method requires less compaction than the California Test Method No. 231, the implication of Skok's studies indicates settlement problems can be minimized by meeting high compaction requirements.

Based upon the foregoing, it is concluded that the present 95 percent relative compaction requirement should be retained.

Cost Analysis

It is extremely difficult to correlate bid prices and changes in specifications or procedures. Figure 10 shows the California Division of Highways Structure Backfill Contract Cost Data and Cost Price Index from 1956 to 1972. There is no apparent correlation between change in specification which occurred in 1960 or the change to the nuclear procedure in 1966. It is too early to tell if the nuclear method using standardized blocks adopted in 1971 will cause any increase in cost. The general increases in cost appear to be due to inflation rather than a change in specification or procedure.

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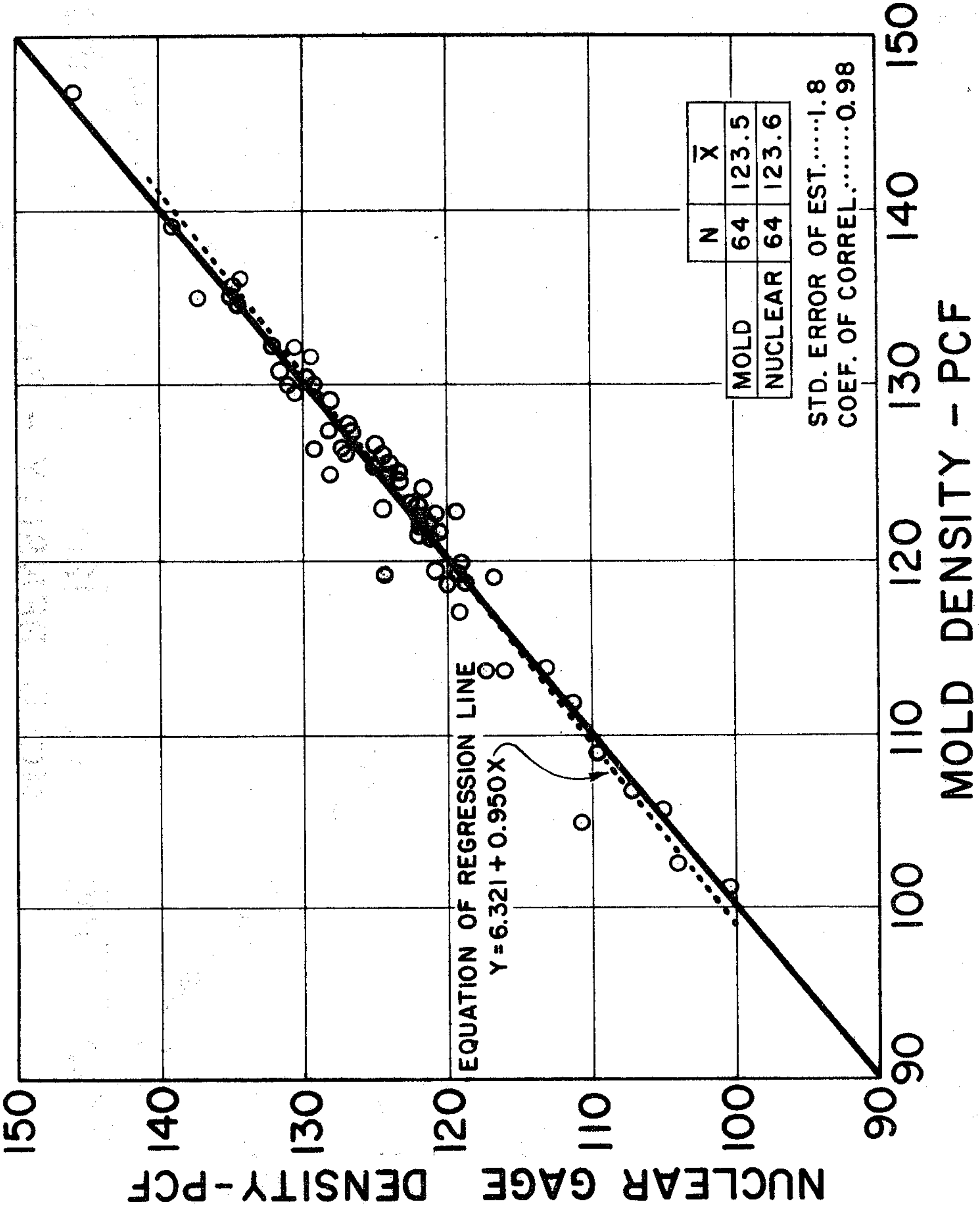
Figure 1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NUCLEAR GAGE DENSITY-PCF
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100
110
120
130
140
150
EQUATION OF REGRESSION LINE
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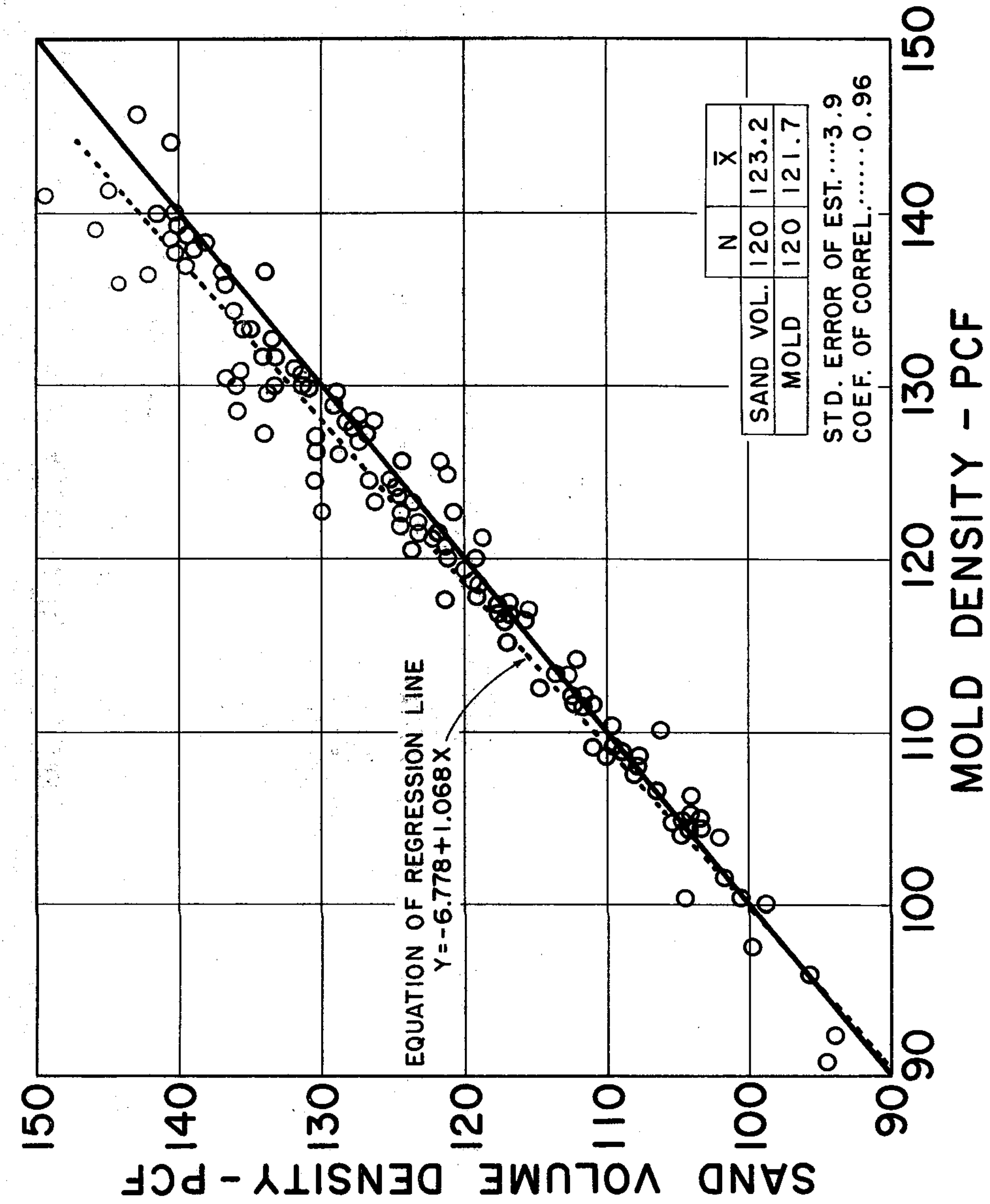
X̄
MOLD 64 123.5
NUCLEAR 64 123.6
STD. ERROR OF EST.......1.8
COEF. OF CORREL........0.98

Figure 2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N
X̄
SAND VOL.
120
123.2
MOLD
120
121.7
STD. ERROR OF EST. 3.9
COEF. OF CORREL. 0.96

Figure 3

EFFECTS OF CONCRETE BLOCKS ON GAGE TESTS

TESTS IN 8" DIRECT TRANSMISSION MODE

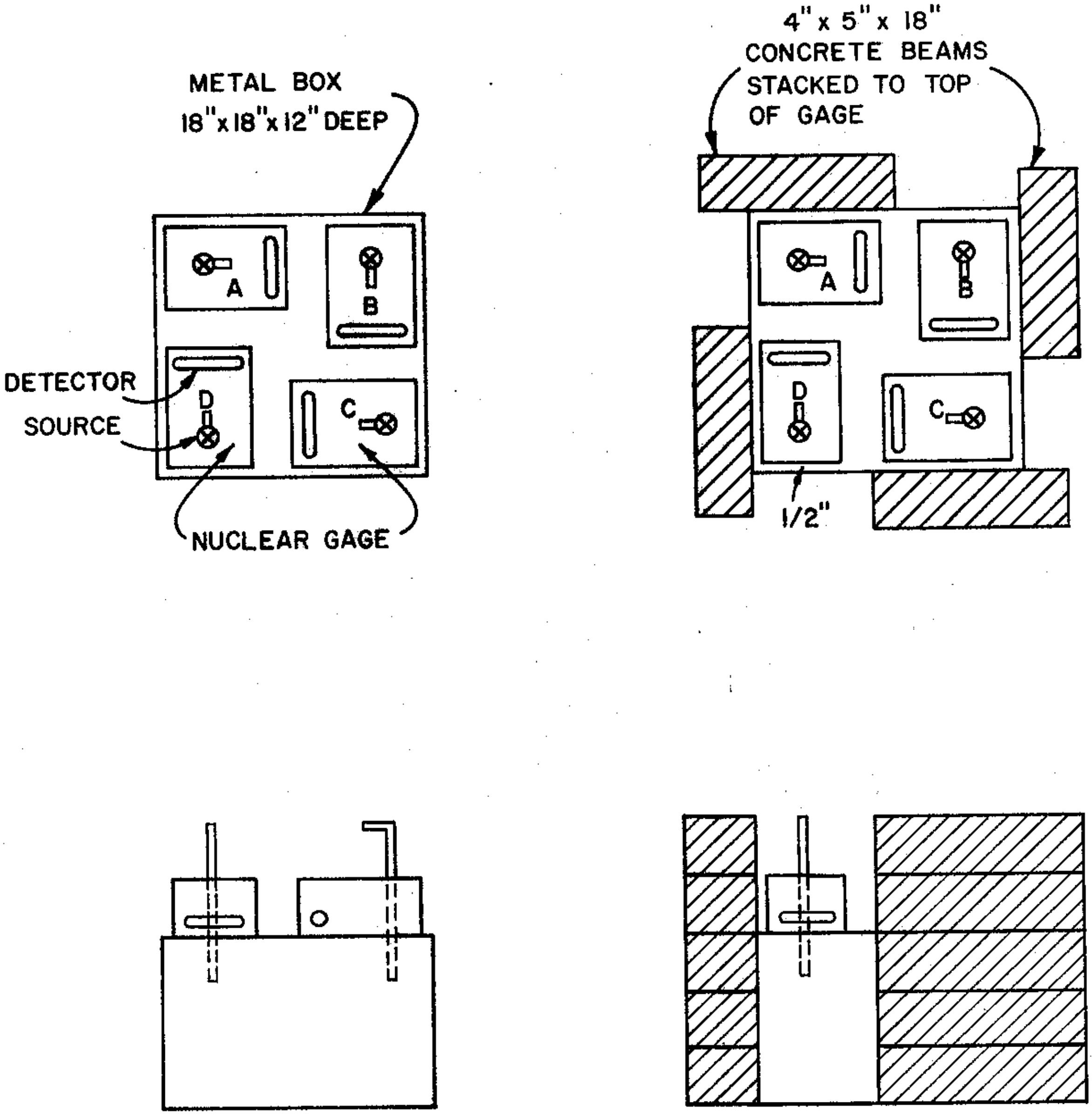


Figure 4

TESTS TO SHOW EFFECT OF ADJACENT MATERIAL

NUCLEAR GAGE IN 8" DIRECT TRANSMISSION MODE

GAGE WAS KEPT IN ONE SPOT AND NOT MOVED DURING EACH SEQUENCE OF TESTS

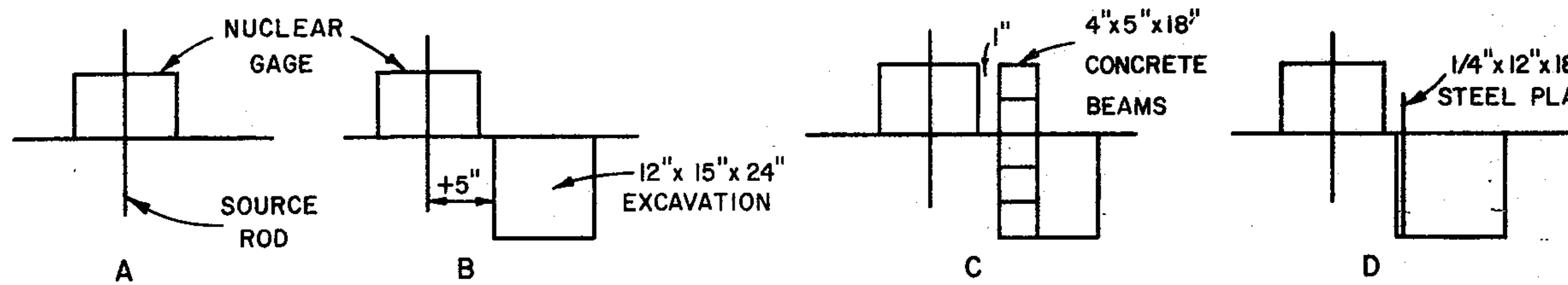
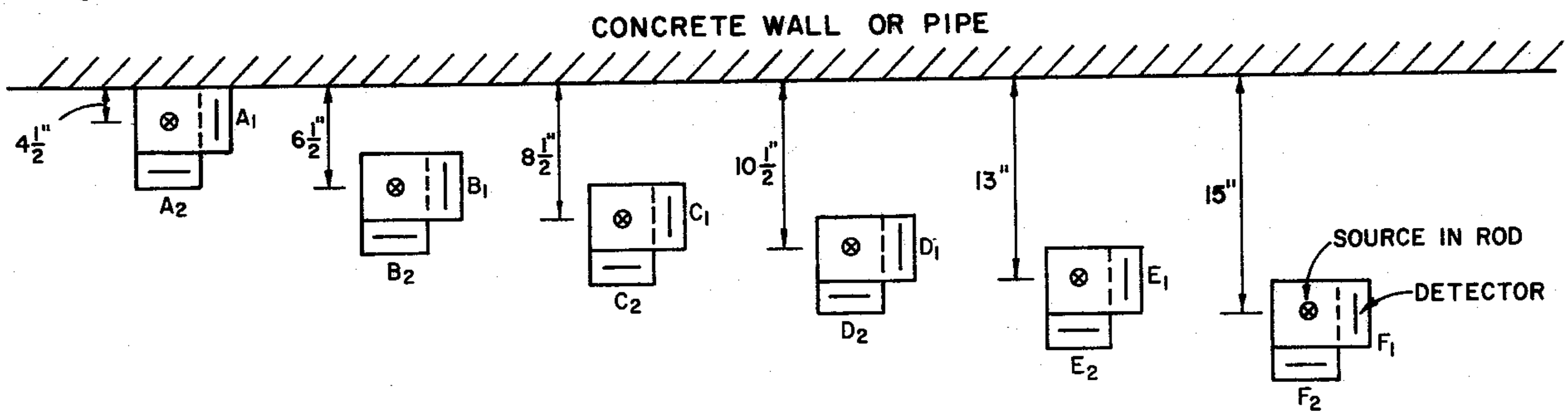


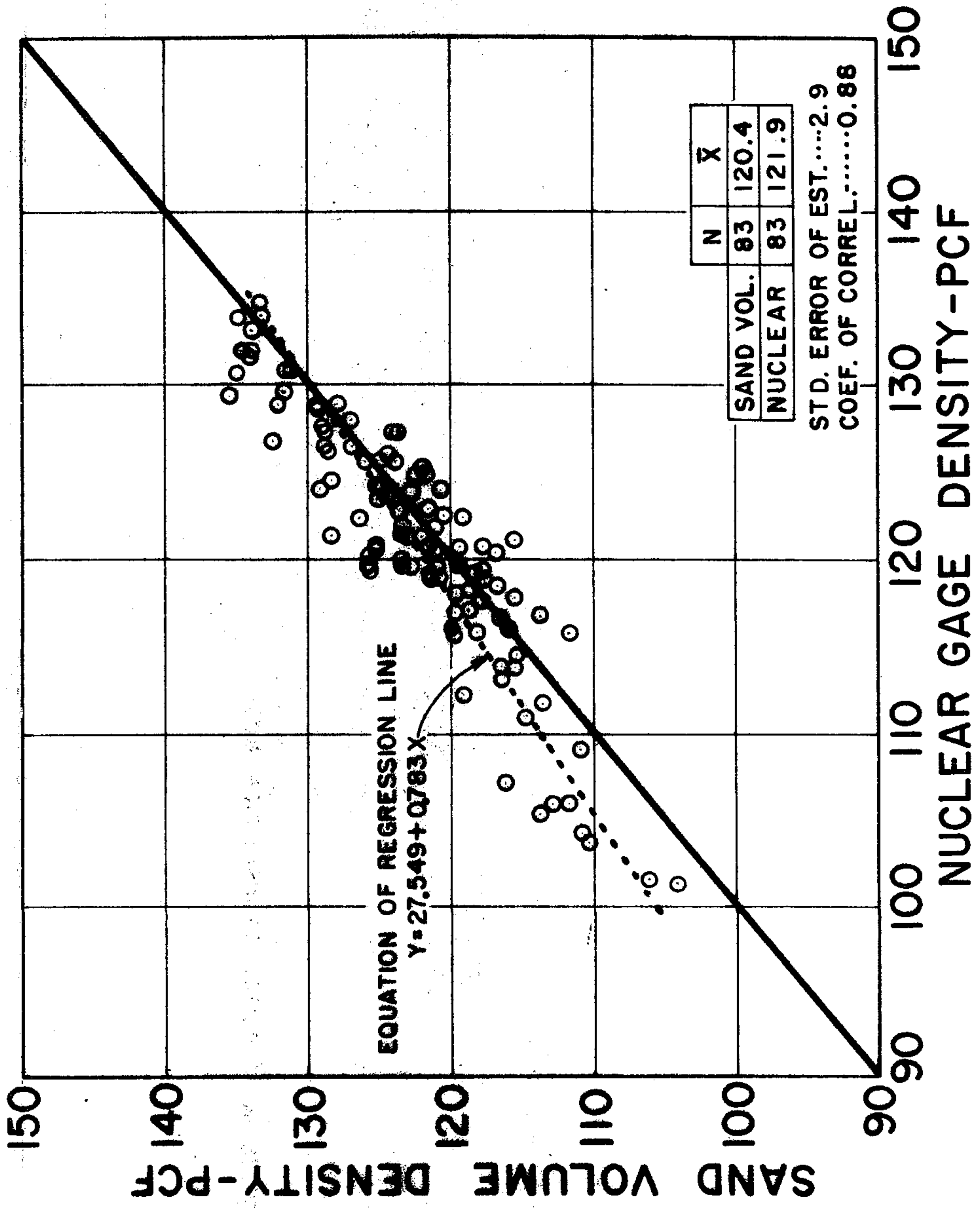
Figure 5

COMPARISON OF DENSITY MEASUREMENTS WITH NUCLEAR & SAND VOLUME



TESTS IN 8" DIRECT TRANSMISSION MODE

Figure 6



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NUCLEAR GAGE DENSITY-PCF
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140
130
120
110
100
90
EQUATION OF REGRESSION LINE
Y=27.549+0783X
N
X̄
SAND VOL.
83
120.4
NUCLEAR
83
121.9
STD. ERROR OF EST.....2.9
COEF. OF CORREL......0.88

Figure 7

NUCLEAR GAGE TESTS ON STRUCTURE BACKFILL MATERIAL NEXT TO RCP

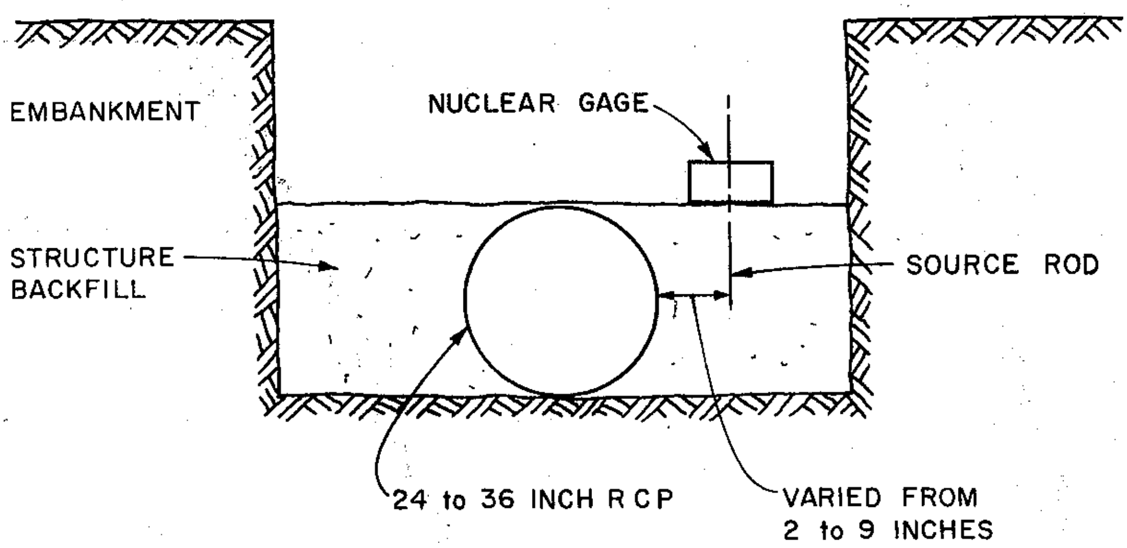
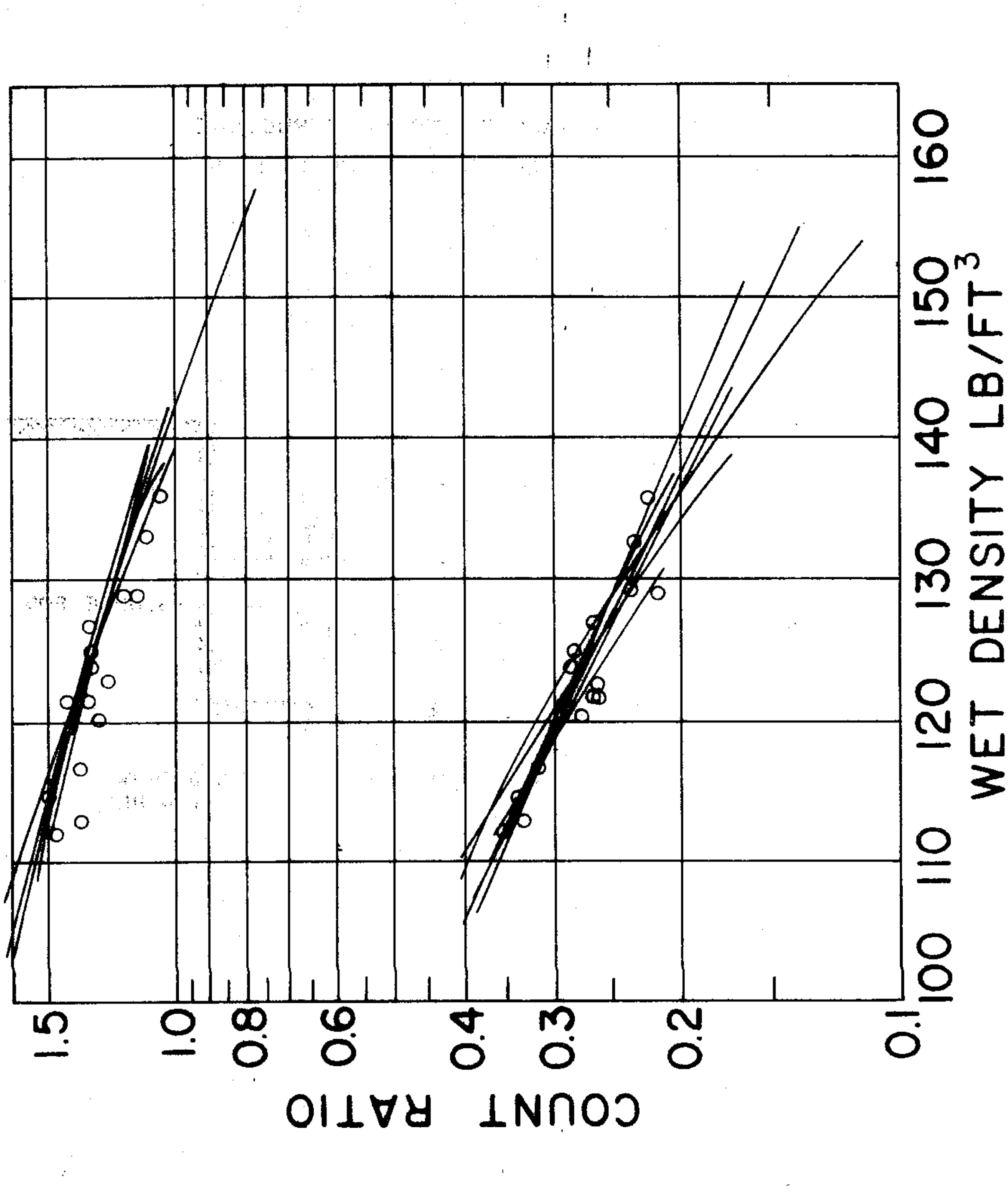


Figure 8



COUNT RATIO
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1.0
0.8
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130
140
150
160

Figure 9

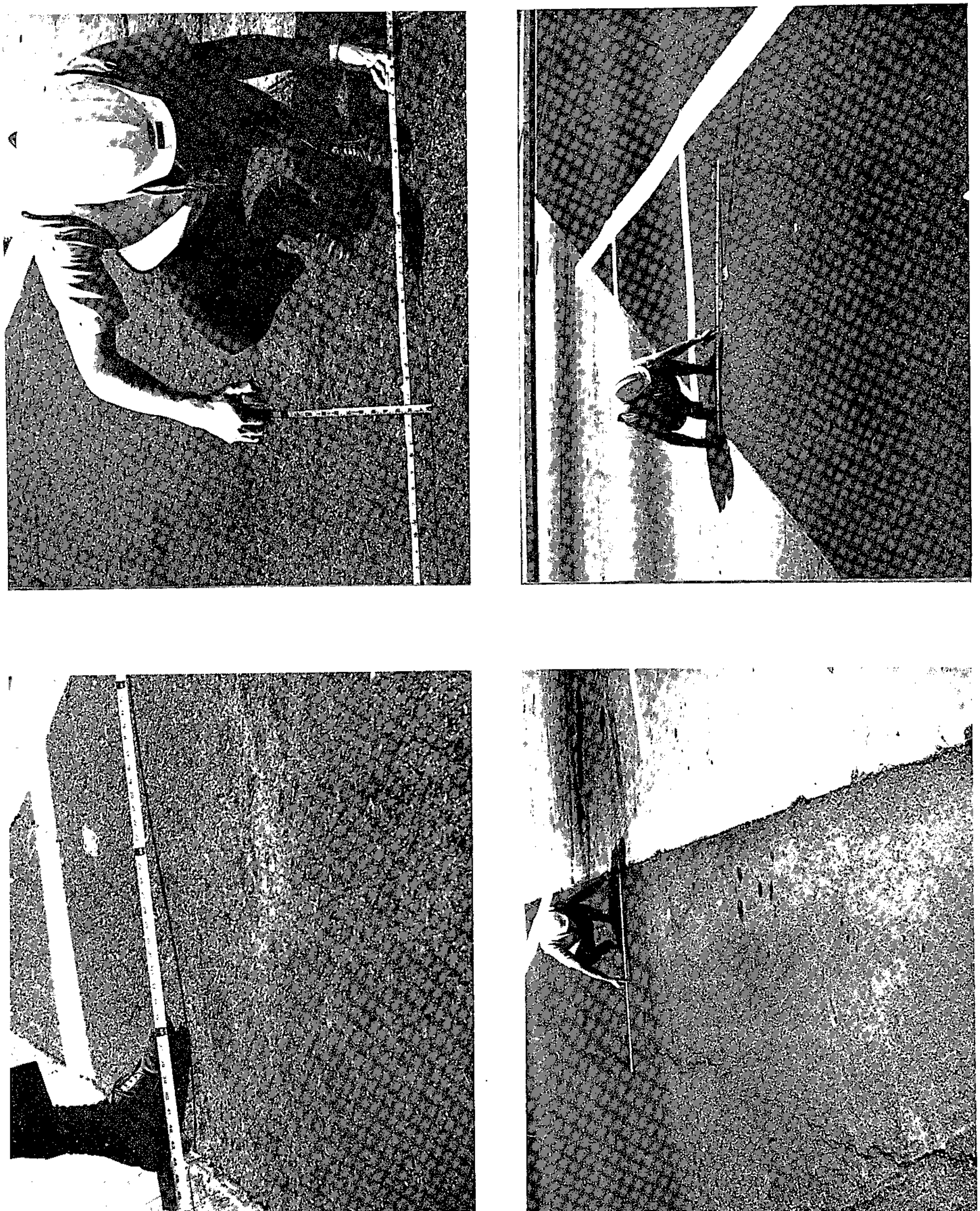
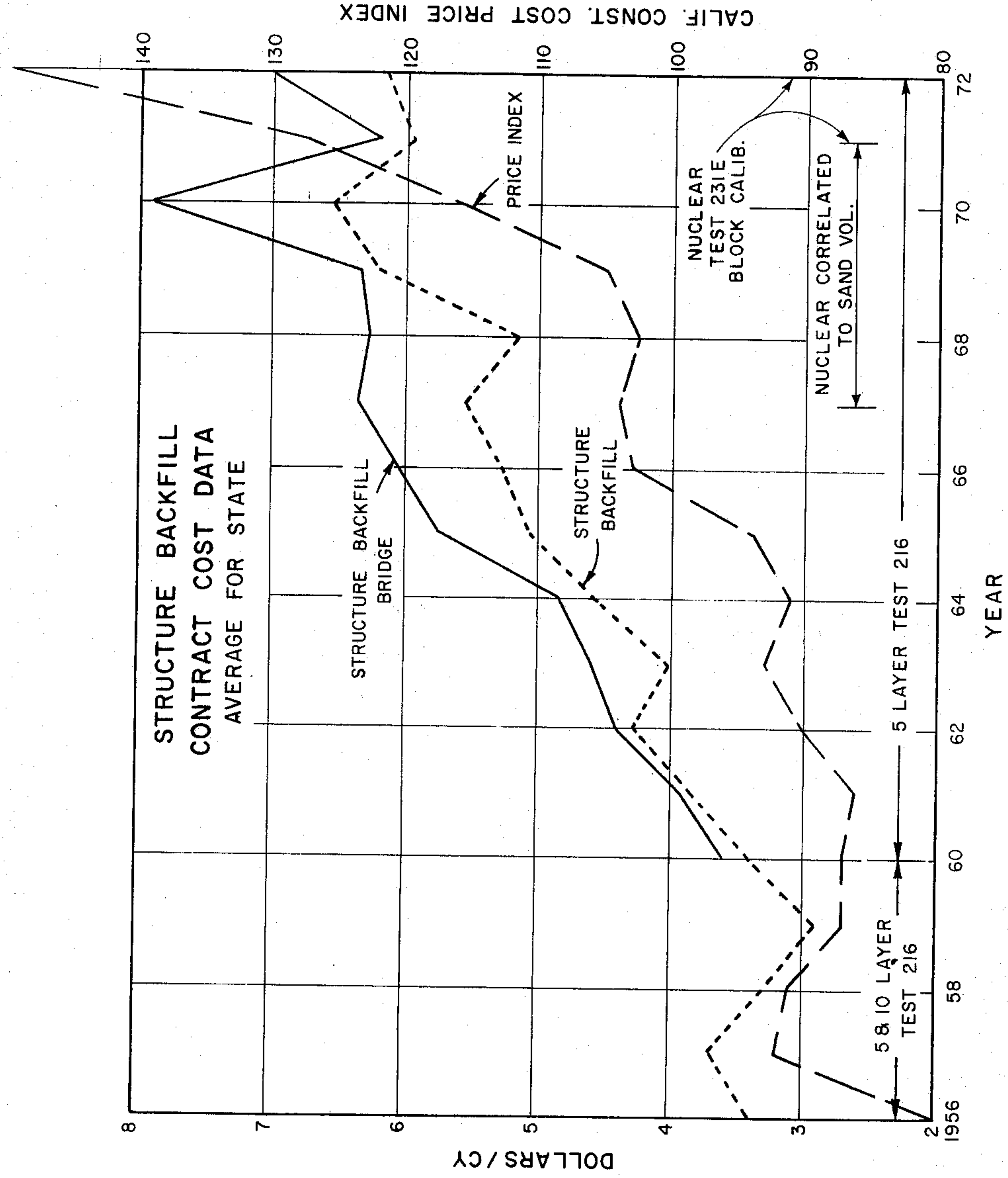


Figure 10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NUCLEAR
TEST 231E
BLOCK CALIB.
NUCLEAR CORRELATED
TO SAND VOL.
STRUCTURE
BACKFILL
STRUCTURE BACKFILL
BRIDGE
5 LAYER TEST 216
5 & 10 LAYER
TEST 216
1956
58
60
62
64
66
68
70
72
YEAR
8
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DOLLARS / CY

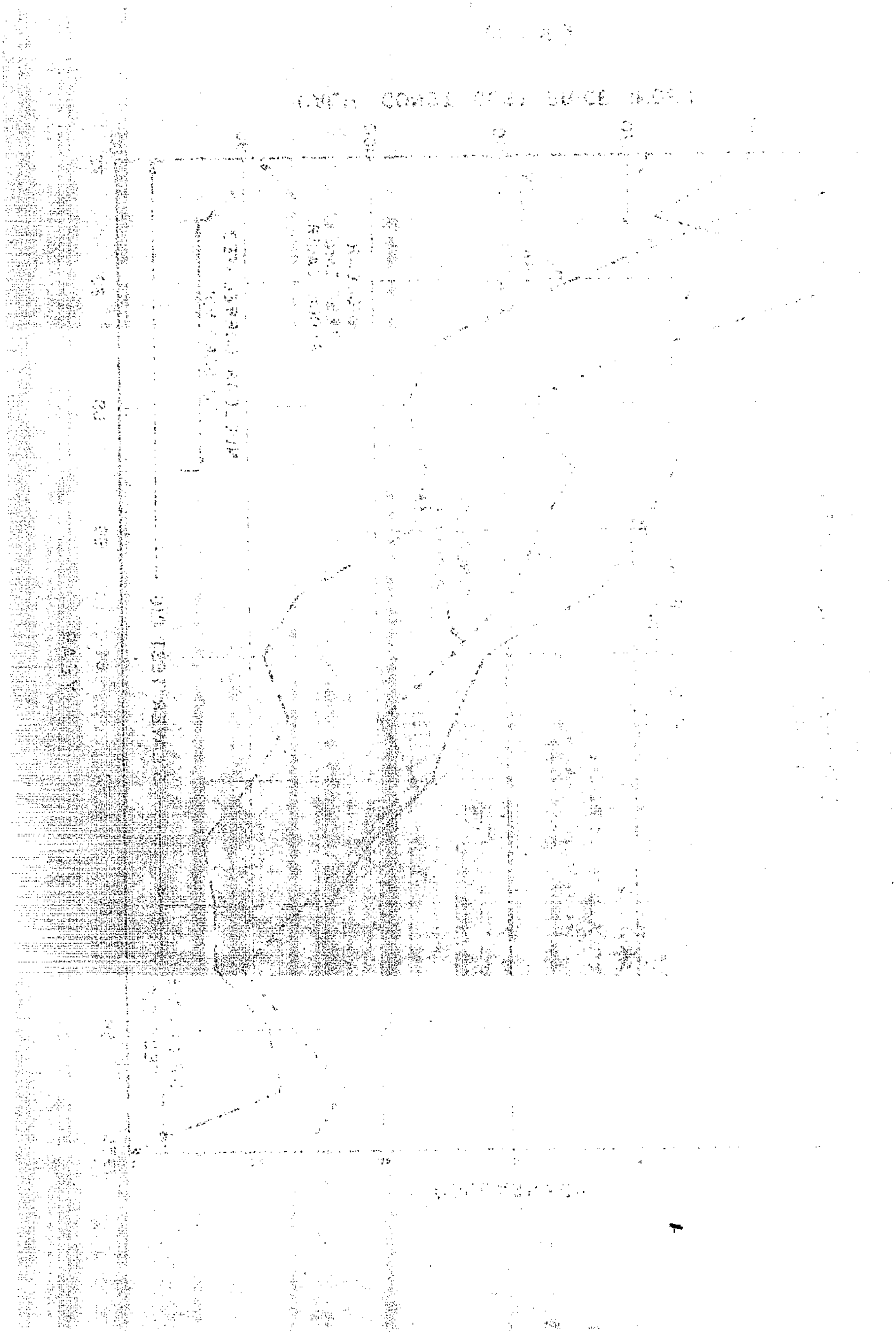

TABLE II

EFFECT OF CONCRETE BLOCKS ON GAGE TESTS-LABORATORY DATA

Tests performed in the 8 inch direct transmission mode.

Tests performed as illustrated on Figure 3.

All nuclear gage densities are the average of 4 measurements.

SANDY MATERIALS FROM PROJECT S

Test No.	Source in Rod Gage Used: W/o Concrete Beams	Source in Rod Gage Used: W/Concrete Beams	Detector in Rod Gage Used: W/o Concrete Beams	Detector in Rod Gage Used: W/Concrete Beams	Sand Volume Average of 2 Tests in Mold	Calculated Density of Mold
1	118.6	118.2	118.6	118.2	119.4	118.4
2	121.5	120.7	119.8	119.9	123.5	121.4
3	125.5	125.1	126.1	125.3	128.5	127.5
4	126.9	126.5	128.3	126.7	127.8	126.7
5	130.8	130.4	130.9	130.8	131.5	130.7
6	125.5	125.5	126.4	125.7	157.4*	127.3
7	128.3	128.1	128.5	126.9	144.0*	128.9
8	120.4	119.9	119.7	119.4	120.0	119.3
9	123.8	123.5	124.1	122.7	125.4	123.3
10	125.6	125.6	125.9	125.9	132.2*	126.9
11	126.8	126.6	127.0	127.1	136.3*	128.0
$\bar{X}$	124.9	124.5	125.0	124.4	125.2	125.3

*Average does not include these tests. These molds were compacted at more than 3 percent over optimum moisture. A very noticeable squeezing of the hole occurred during excavation of the hole for the sand volume test.

TABLE II
(continued)

SILTY SAND AND GRAVEL MATERIAL (VOLCANIC) FROM PROJECT W

Test No.	Source in Rod Gage Used W/o Concrete Beams	Source in Rod Gage Used W/Concrete Beams	Detector in Rod Gage Used W/o Concrete Beams	Detector in Rod Gage Used W/Concrete Beams	Sand Volume 1 Test in Mold	Calculated Density of Mold
1	130.4	130.0	131.3	132.0	133.0	130.2
2	130.8	130.8	130.5	130.2	131.2	130.0
3	113.8	113.2	112.4	111.9	112.1	112.7
4	122.3	122.0	-	-	130.0*	122.9
$\bar{X}$	124.3	124.0	124.7	124.7	125.4	124.0

SILTY SAND AND SOME GRAVEL FROM PROJECT N

Test No.	Source in Rod Gage Used W/o Concrete Beams	Source in Rod Gage Used W/Concrete Beams	Detector in Rod Gage Used W/o Concrete Beams	Detector in Rod Gage Used W/Concrete Beams	Sand Volume Average of 2 Tests in Mold	Calculated Density of Mold
1	119.3	119.2	117.7	117.4	121.7	120.0
2	128.3	128.0	-	-	136.2*	131.4
3	129.8	129.2	130.2	129.9	133.2	131.2
4	124.7	124.3	126.1	125.8	126.4	126.0
$\bar{X}$	125.5	125.2	124.7	124.4	127.1	127.2

*Average does not include these tests. These molds were compacted at more than 2 percent over optimum moisture. A very noticeable squeezing of the hole occurred during excavation of the hole for the sand volume test.

TABLE II
(continued)

SILTY SAND MATERIAL FROM PROJECT T

Test No.	Source in Rod Gage Used: W/o Concrete Beams	Source in Rod Gage Used: W/Concrete Beams	Detector in Rod Gage Used: W/o Concrete Beams	Detector in Rod Gage Used: W/Concrete Beams	Sand Volume Average of 2 Tests in Mold	Calculated Density of Mold
1	119.3	119.2	117.6	117.6	121.7	120.0
2	128.3	127.3	-	-	136.2*	131.4
3	129.8	129.2	130.2	129.9	133.2	131.2
4	124.7	124.3	126.1	125.8	126.4	126.0
$\bar{X}$	125.5	125.0	124.6	124.4	127.1	127.2

SANDY SOIL FROM PROJECT M

Test No.	Source in Rod Gage Used: W/o Concrete Beams	Source in Rod Gage Used: W/Concrete Beams	Detector in Rod Gage Used: W/o Concrete Beams	Detector in Rod Gage Used: W/Concrete Beams	Sand Volume 1 Test in Mold	Calculated Density of Mold
1	121.3	121.2	120.8	120.5	122.9	122.8
2	121.1	121.0	117.5	116.2	123.6	121.9
3	121.9	121.4	-	-	136.0*	123.0
4	121.3	120.8	118.6	118.3	121.2	122.0
5	122.5	122.3	120.0	119.6	124.4	124.6
6	123.8	123.1	122.1	121.3	125.0	124.7
7	121.5	121.0	-	-	126.7*	123.0
$\bar{X}$	121.9	121.5	119.8	119.2	123.4	123.1

*Average does not include these tests. These molds were compacted at more than 2 percent over optimum moisture. A very noticeable squeezing of the hole occurred during excavation of the hole for the sand volume test.

TABLE III

EFFECT OF ADJACENT MATERIALS ON GAGE TESTS - FIELD DATA

Tests performed as illustrated on Figure 4.

Tests performed in 8 inch direct transmission mode.

Project	Location	Type of Material	Type of Gage	Nuclear Readings Under Conditions A	B	C	D	Sand Volume
M	1	Sandy	Source in Rod	117.0	117.1	116.9		119.9
	2	"	Detector in Rod	114.9	114.2	114.9		118.8
T	1	Silty Sand	Source in Rod	121.7	122.4	122.5	122.0	
	2	" "	"	124.9	125.0	125.4	125.2	
	3	" "	Detector in Rod	110.0	110.0	110.0	110.0	
	4	" "	"	118.0	118.4	117.6	118.1	
W	1	Volcanic	Source in Rod	115.2	114.6	115.2	115.6	123.8
	2	"	Detector in Rod	112.6	112.6	112.6	112.6	119.9
N	1	Silty Sand	Source in Rod	120.8	123.4	123.4		119.1
	2	"	"	121.4	121.3	121.2		121.9
	3	"	"	120.4	120.4	120.3		116.7
S	1	Sandy	Detector in Rod	118.0	118.6	117.4	118.6	
	2	"	"	115.5	113.6	112.4	113.0	
	3	"	Source in Rod	116.2	116.3	116.2	116.3	
	4	"	"	111.8	113.0	113.1	112.8	

TABLE IV

TESTS PERFORMED NEXT TO CONCRETE WALLS AND PIPES - FIELD DATA

TESTS PERFORMED NEXT TO 12" THICK CONCRETE WALL USING NUCLEAR

PROJECT T

See Figure 5 for general test configuration.

Silty sand material for embankment and backfill.

Source in the rod gage used.

Tests performed in the 8" direct transmission mode.

Location	A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2	F_1	F_2
1	113.8	111.2	115.4	115.6	116.2	119.4	115.8	119.4	124.8	125.8
2	120.2	125.4	122.4	124.0	125.4	125.8	123.4	125.4	121.2	125.2
3	119.2	118.4	123.8	121.1	120.0	123.9	120.3	125.4	121.1	118.9
4	117.2	120.6	119.6	123.9	117.4	121.0	120.1	118.2	116.8	117.6
5	123.0	124.5	128.6	125.9	124.2	124.6	126.5	127.4	125.2	125.8
6	114.6	117.0	113.8	114.2	117.8	121.6	118.8	121.2	125.4	125.9
7	122.7	122.6	115.3	124.9	123.3	123.1	125.7	124.5	126.8	126.8
8	122.2	119.7	121.7	118.9	118.1	119.2	117.5	119.7	123.4	123.2
$\bar{X}$	119.1	119.9	120.1	121.1	120.3	122.3	121.0	122.7	123.1	123.7

TABLE IV
(continued)

TESTS PERFORMED NEXT TO 12" THICK CONCRETE WALL USING NUCLEAR AND SAND VOLUME

PROJECT T

See Figure 5 for general test configuration.

Silty sand material for embankment and backfill.

Source in the rod gage used.

Tests performed in the 8" direct transmission mode.

Location	A_1	S.V.	B_1	B_2	C_1	C_2	S.V.	E_1	E_2	F_1	F_2	S.V.
1	125.5	126.2	124.8	124.8	123.8	126.0	129.0	123.8	128.4	128.9	128.4	128.2
2	124.2	128.3	125.4	126.4	128.2	126.6	127.2	128.2	127.7	127.7	127.7	123.5
3	121.0	121.7	126.4	124.4	121.5	125.2	123.2	124.8	129.2	123.7	121.9	122.7
4	125.7	124.3	122.2	126.7	120.1	124.4	125.9	124.1	121.8	120.7	122.7	117.4
5	122.5	126.7	127.9	126.5	125.4	127.4	125.0	127.9	128.0	126.3	127.5	126.8
6	116.1	116.2	114.3	120.0	121.3	125.9	122.5	121.5	126.4	127.1	127.9	132.6
$\bar{X}$	122.5	123.9	123.5	124.8	123.4	125.9	125.5	125.1	126.9	125.7	126.0	125.2

TABLE IV
(continued)

TESTS PERFORMED NEXT TO 120" CMP AT SPRINGLINE USING THE NUCLEAR GAGE AND SAND VOLUME

PROJECT N

See Figure 5 for general test configuration.

Silty sand and some gravel used for embankment and backfill.

Source in the rod gage used.

Tests performed in the 8" direct transmission mode.

	POSITION OF GAGE											
	A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2	E_1	E_2	F_1	F_2
Nuclear	118.6	118.4	120.2	121.8	120.6	121.2	119.6	120.7	118.0	119.6	121.0	121.6
$\bar{X}$	118.5		121.0		120.9		120.2		118.8		121.3	
Sand Volume	118.1		115.4		119.2		118.0		116.9		120.8	

TABLE IV
(continued)

TESTS PERFORMED NEXT TO 12" THICK CONCRETE WALL USING NUCLEAR

PROJECT N

See Figure 5 for general test configuration.

Silty sand and some gravel used for embankment and backfill.

Source in the rod gage used.

Tests performed in the 8" direct transmission mode.

	POSITION OF GAGE									
Location	A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2	E_1	E_2
I	116.4	114.6	117.2	116.8	116.6	116.2	117.8	117.8	115.0	118.0
II	116.4	116.6	121.0	122.2	125.4	126.4	124.1	123.1	121.6	122.2
III	116.0	118.4	118.4	119.0	115.6	115.2	119.8	119.6	117.2	117.6
$\bar{X}$	116.3	116.5	118.9	119.3	119.2	119.3	120.6	120.2	117.9	119.3

TABLE IV
(continued)

TESTS PERFORMED NEXT TO 12" THICK CONCRETE WALL USING NUCLEAR AND SAND VOLUME

PROJECT M

See Figure 5 for general test configuration.

Silty sand material for embankment and backfill.

Source in the rod gage used.

Tests performed in the 8" direct transmission mode.

Location	A_1	A_2	B_1	B_2	S.V.	C_1	C_2	S.V.	D_1	D_2	F_1	F_2	S.V.
I	103.2	109.9	107.6	110.5	111.9	108.8	113.1	114.5	112.4	116.1	117.4	116.6	113.5
II	105.2	104.8	106.5	105.2	111.8	106.9	107.5	-	106.0	106.4	-	-	-
III	104.5	-	108.9	-	-	111.8	-	113.5	111.7	-	-	-	-

TABLE VI

TESTS PERFORMED NEXT TO CONCRETE PIPES USING NUCLEAR AND SAND VOLUME

TESTS PERFORMED ALONG 24 INCH RCP

PROJECT S

See Figure 7 for test configuration.

Sandy material was used for structure backfill.

Source or detector rod was 7 inches from the RCP.

The gage source-detector axis was placed parallel to the flow line of the pipe.

Area	Site	8" Direct Transmission Test Mode: Source in Rod Gage	8" Direct Transmission Test Mode: Detector in Rod Gage	Sand Volume
I	A	120.7	120.5	125.5
	B	118.6	119.2	121.8
	C	121.9	122.4	123.5
	D	119.8	121.7	123.5
	E	123.8	124.9	120.9
	F	119.4	118.6	126.0
	$\bar{X}$	120.7	121.2	123.5
II	A	123.8	123.3	125.0
	B	129.8	128.0	132.0
	C	123.7	122.7	124.8
	D	128.8	128.8	129.1
	E	126.4	123.3	128.5
	F	127.6	127.7	128.8
	$\bar{X}$	126.7	125.6	128.0
III	A	123.8	123.3	125.0
	B	129.8	128.0	132.0
	C	123.7	122.7	124.8
	D	128.8	128.8	129.1
	E	126.4	123.3	128.5
	F	127.6	127.7	128.8
	$\bar{X}$	126.7	125.6	128.0

TABLE VI
(continued)

TESTS PERFORMED ALONG 36 INCH RCP USING
NUCLEAR AND SAND VOLUME

PROJECT M

See Figure 7 for test configuration.

Sandy material was used for structure backfill.

Source or detector rod was 6 inches from the RCP.

The gage source-detector axis was placed parallel to the flow line of the pipe.

Area	Site	8" Direct Transmission Test Mode: Source in Rod Gage	8" Direct Transmission Test Mode: Detector in Rod Gage	Sand Volume
I	A	121.0	121.6	
	B	117.0	118.8	118.2
	C	120.8	119.8	
	D	121.8	121.6	128.0
	E	122.8	124.2	
	F	122.4	123.2	123.5
	$\bar{X}$	121.0	121.5	123.2
II	A	120.0	120.6	
	B	119.6	120.0	123.0
	C	114.4	115.2	
	D	117.8	118.1	119.5
	E	115.4	116.0	
	F	119.6	119.4	118.3
	$\bar{X}$	117.8	116.2	120.3

TABLE VI
(continued)

TESTS PERFORMED ALONG 30 INCH RCP USING
NUCLEAR AND SAND VOLUME

PROJECT M

See Figure 7 for test configuration.

Sandy material used for structure backfill.

The source rod was 2 inches from the RCP.

Source in the rod type of gage used.

Source-detector axis was placed parallel and perpendicular to the flow line of the pipe at various locations.

Area	Site	8" Direct Transmission Test Mode: Source Det. Axis Parallel to Pipe	8" Direct Transmission Test Mode: Source Det. Axis Perpendicular to Pipe	Sand Volume
III	A	106.7	104.7	112.8
	B	106.0	108.1	115.7
	C	101.7	105.1	110.1
	$\bar{X}$	104.8	106.0	112.9
IV	A	103.6	104.0	110.4
	B	103.4	108.2	112.0
	C	112.0	111.3	116.0
	$\bar{X}$	106.3	107.8	112.8

TABLE VI
(continued)

TESTS PERFORMED ALONG 30 INCH RCP USING
NUCLEAR AND SAND VOLUME

PROJECT W

See Figure 7 for test configuration.

Volcanic material used for structure backfill.

The source-detector axis was placed parallel to the flow line of the pipe.

Source in the rod gage in 8" direct transmission test mode.

Site	Rod Distance From Pipe				Sand Volume
	4"		9"		
A	128.4	129.5*	129.5		135.5
B	122.8		123.0	122.0*	
C	112.3		110.5		114.1

*Job gage - detector in rod.

TABLE VII

NUCLEAR VS. SAND VOLUME - FIELD TESTS AWAY FROM STRUCTURES ON STRUCTURE BACKFILL MATERIAL

PROJECT S

Tests performed away from all obstructions at 6 locations.

Fine sand and silty material used for backfill.

Site	8" Direct Transmission Test Mode: Source in Rod Gage Used	8" Direct Transmission Test Mode: Detector in Rod Gage Used	Sand Volume
A	130.8	131.7	134.8
B	134.2	136.1	133.2
C	130.7	131.7	131.1
D	133.2	131.1	134.0
E	125.2	126.1	122.2
F	131.7	132.0	134.1
$\bar{X}$	131.0	131.5	131.6

TABLE VII
(continued)

COMPARISON OF NUCLEAR AND SAND VOLUME
TESTS ON STRUCTURE BACKFILL MATERIAL

PROJECT T

Tests performed in open area away from all obstructions.

Silty sand used for backfill.

Source in the rod gage used.

Tests performed in the 8" direct transmission mode.

Site	Nuclear	Sand Volume
A	125.6	124.1
B	124.7	122.2
C	127.4	123.7
D	120.0	119.9
E	122.9	121.6
F	122.4	120.6
$\bar{X}$	123.8	122.0

TABLE VIII

SAND VOLUME TEST DATA FROM PAST JOBS

District	Contract	No. of Tests	% Relative Compaction Mean	Percent of Tests Below 95	94	93	92
03	03-074024	191	95.5	37.2	30.4	23.0	19.4
	03-056514	96	94.3	41.7	31.3	27.1	20.8
	03-100874	117	92.7	65.0	53.8	42.7	33.3
	03-020964	101	95.3	31.7	28.7	25.7	20.8
	03-033314	85	96.2	29.4	12.9	5.9	4.7
		590	94.8	41.4	32.4	25.6	20.5
04	04-120334	370	95.4	38.4	28.1	20.5	14.1
	63-4T13C78	67	96.4	20.9	17.9	16.4	9.0
	04-120224	30	91.8	70.0	60.0	53.3	43.3
	62-4T13C25	72	93.6	48.6	41.7	37.5	31.9
	63-4T13C53	45	92.7	53.3	42.2	37.8	37.8
	04-118134	27	95.9	25.9	22.2	22.2	14.8
	04-208404	6	92.9	100.0	33.3	33.3	33.3
		617	94.9	40.4	31.0	25.1	19.0
07	07-248124	24	93.5	33.3	33.3	20.8	20.8
	07-033844	88	94.4	36.4	31.8	20.5	12.5
	64-7V13C15	58	95.7	36.2	34.5	22.4	13.8
	07-009424	443	95.8	21.4	18.7	14.2	10.8
		613	95.5	25.4	22.7	16.2	11.7
08	08-039644	114	95.1	31.6	31.6	28.1	20.2
	08-037424	235	96.3	24.7	19.6	17.4	12.3
	08-037474	104	97.0	19.2	16.3	8.7	5.8
	08-060214	74	97.0	17.6	12.2	9.5	6.8
	08-096504	112	94.8	23.2	20.5	19.6	17.9
		639	96.0	24.0	20.5	17.4	13.0
10	64-10T13C9	33	94.8	45.5	42.4	21.2	15.2
	63-10T13C9F	156	96.0	30.1	23.1	19.2	14.1
	62-10T13C4	67	92.8	62.7	59.7	52.2	37.3
		256	95.0	40.6	35.2	28.1	20.3
11	64-11V13C1I	201	94.2	36.8	30.3	24.4	20.9
	11-037574	68	95.2	25.0	20.6	19.1	11.8
	11-037524	467	96.8	20.8	14.3	8.8	6.4
	64-11V19C1P	105	97.1	14.3	8.6	7.6	5.7
	11-039314A	58	97.2	31.0	22.4	12.1	6.9
	11-039314B	57	95.5	33.3	33.3	26.3	24.6
	11-038044A	42	97.5	9.5	7.1	7.1	4.8
	11-038044B	66	97.2	18.2	13.6	7.6	6.1
		1,064	96.2	24.1	18.3	13.3	10.3
		3,779	95.6	30.8	24.8	19.3	14.7

TABLE IX

NUCLEAR GAGE DATA FROM PAST JOBS CALIBRATED TO SAND VOLUME

District	Contract	No. of Tests	% Relative Compaction Mean	Percent of Tests Below 95	94	93	92
01	01-057644	43	96.4	23.3	18.6	4.7	2.3
	01-022324	105	95.5	21.0	19.0	17.1	15.2
		148	95.8	21.7	18.9	13.5	11.5
03	03-099324	93	95.4	28.0	17.2	15.1	14.0
	03-042434	42	96.4	14.3	11.9	4.8	4.8
	03-100844	89	94.2	44.9	40.4	30.3	19.1
		224	95.1	32.1	25.4	19.2	14.3
04	04-208404	175	97.1	15.4	8.0	6.3	3.4
	04-136444	201	95.4	28.4	20.4	12.9	9.5
		376	96.2	22.3	14.6	9.8	6.6
07	07-063764	24	95.5	25.0	20.8	12.5	8.3
08	08-051634	349	95.1	38.7	30.1	23.8	19.5
	08-046854	254	95.6	21.7	16.5	10.6	7.1
		603	95.4	31.5	24.4	18.2	14.3
11	11-122404	407	95.5	29.2	22.4	14.0	10.6
	11-086034	177	95.9	27.1	18.1	11.3	9.6
		584	95.6	28.6	21.1	13.2	10.3
		1,959	95.6	28.1	21.2	14.8	11.3

TABLE X

NUCLEAR GAGE TEST DATA FROM CURRENT JOBS
CALIBRATED TO STANDARD BLOCKS

			% Relative Compaction				
				Percent of Tests Below			
District	Contract	No. of Tests	Mean	95	94	93	92
01	01-047224	23	94.9	26.1	13.0	8.7	8.7
02	02-035804	167	94.5	38.3	32.9	25.7	19.2
	02-021524	28	94.1	34.4	34.4	31.0	17.3
		195	94.4	37.7	33.1	26.5	18.9
03	03-122624	52	93.4	59.6	57.7	36.5	17.3
	03-136814	87	93.1	64.4	55.2	47.1	34.5
	03-052224	286	94.5	36.7	26.9	21.3	16.1
	03-047884	44	93.2	52.3	50.0	38.6	31.8
	03-052264	185	93.8	44.9	38.4	31.9	21.6
		654	93.9	45.6	37.9	30.1	21.3
04	04-419254	49	94.5	34.7	28.6	20.4	14.3
	04-419264	53	94.8	39.6	28.3	24.5	17.0
	04-208404	110	96.0	12.7	5.5	5.5	4.5
	04-279514	71	93.0	66.2	50.7	39.4	28.2
		283	94.8	35.0	25.1	20.1	14.5
05	05-022024	180	96.0	25.0	20.0	15.6	12.2
07	07-248114	140	94.1	35.7	30.0	27.1	18.6
	07-155014	364	94.7	31.3	26.4	19.2	13.2
	07-271414	141	94.3	38.3	34.0	29.1	21.3
	07-155024	320	95.0	23.1	19.1	13.7	10.3
		965	94.9	30.2	25.6	20.0	14.2
08	08-046854	793	94.5	42.9	25.1	13.2	6.2
10	10-030104	203	95.6	36.0	20.0	12.8	7.9
	10-150804	52	92.9	71.2	48.1	40.4	26.4
	10-056684	67	94.7	38.8	28.4	11.9	6.0
		322	95.0	42.3	26.3	17.1	10.5
11	11-086044	94	93.8	55.3	46.8	33.0	20.2
		3,509	94.6	38.2	28.4	20.5	13.7

STATE OF CALIFORNIA—TRANSPORTATION AGENCY RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

October 1971

Project 762504-641139A

Mr. J. L. Beaton
Materials and Research Engineer

Dear Sir:

Submitted herewith is a research report titled:

NUCLEAR GAGE DENSITY TESTS NEXT

TO STRUCTURES

TRAVIS SMITH
Principal Investigator

A. D. HIRSCH and M. M. HATANO
Co-Investigators

Very truly yours,

Travis Smith

Travis Smith
Assistant Materials and
Research Engineer

NUCLEAR GAGE DENSITY TESTS
NEXT TO STRUCTURES

October 13, 1971

PROBLEM

There are some indications that nuclear gage density tests in the direct transmission mode could be affected by being close to a concrete structure.

OBJECTIVE

Explore any effect that a concrete wall may have on nuclear density measurements when testing in the 8 inch direct transmission mode.

TESTING PLAN

Phase I of the work was performed in the laboratory and Phase II in the field.

PHASE I

A portaprobe gage was placed on a concrete block and a density of 117.2 pcf was measured (Figure 1). The detector rod was 5-inches from the outer edge of the concrete block. The problem was to determine if any radiation could be backscattered to the detector rod if there was additional thickness of material in front of the rod.

Aluminum sheets (1/2" x 16" x 24") weighing 172 pcf were available from a previous study. These were used instead of concrete slabs since addition of 1/2 inch thickness of high density aluminum would indicate the nominal thickness at which there would be some effect.

Subsequent measurements were made with varying thickness of aluminum sheets against the side of the concrete block. The data showed no more than a 0.5 pcf change without and with the aluminum sheets. This is within normal test variation.

From this experiment, it is concluded that significant amounts of radiation are not being backscattered to the detector resulting in a change of density measurement.

Figure 2 shows the same type experiment with 4 inches of material between the detector rod and the outer edge of the concrete block. Subsequent addition of aluminum plates showed no significant change in densities.

Figure 3 shows a test condition where the aluminum sheets were placed against the block about 9-1/2 inches away from and parallel to the source-detector rod axis. There was no significant change in density with or without the plates against the side of the block.

Figure 4 shows the same situation as Figure 3 except that the aluminum sheets are about 5-1/2 inches away from and parallel to the source-detector rod axis. There is no significant change in density with or without the plates against the side of the block.

Figure 5 shows a test condition where the side of the gage extends about 1 inch beyond the edge of the block. The addition of a 1/2 inch sheet of aluminum showed a 2.2 pcf increase in density. However, when 2 or more inches of aluminum were added, there was no significant change in density.

Figure 6 shows a test situation where the detector rod is placed over the edge of the block and exposed to the air. The density measured in this manner is 103.4 pcf. Subsequent additions of 1/2 inch thick aluminum plates placed perpendicular to the source-detector rod axis and against the detector rod causes a decrease in density. This change in density appears to level off after 3-1/2 inches of aluminum is placed against the detector rod.

Figure 7 shows a similar test situation as shown in Figure 6 except that magnesium sheets weighing 110 pcf were used. The change in densities due to addition of magnesium plates is not significant at about 3 or more inches.

Figures 1 through 7 indicate that under these laboratory conditions, there is no significant increase in radiation measured beyond about 4 inches of material in front of the detector rod or to the side of the source-detector rod axis.

Tests were also performed with the gage on a standard concrete block in normal position for calibration. Then 6" x 6" x 20" concrete beams were placed on the concrete block and against one side, 2 sides, 3 sides and 4 sides of the portaprobe gage. Tests performed under these conditions indicate a maximum of 0.7 pcf variation. It is concluded that in the field concrete walls near the side of the gage would not significantly affect density measurements being made on the structure backfill material.

PHASE II

Figure 8 shows a schematic of a testing program carried out on a project in District 8 near Colton. The tests were staggered along the wall. Each location represents one series of tests along one portion of the concrete wall. The material was sandy with some rocks.

Due to variables in compaction, materials and testing, a series of tests were taken to show trends. Where possible, tests were taken so that the source-detector rod axis was parallel to (A series) and perpendicular to (B series) the wall with the rod closest to the wall in the perpendicular position.

A tabulation of the data on Table I shows that there is some variation when comparing individual tests but in general, the averages are not significantly different from each other. However, the averages at A_3 and B_3 (detector 6" from wall) show a difference of 2.2 pcf with the source-detector rod parallel to the wall giving the slightly higher average density.

Figure 9 shows a schematic of a testing program carried out on a project in District 10 near the Route 120-Interstate 5 interchange located next to the San Joaquin River. The tests were staggered along the wall and a series of tests were made at each location. The material was sand with 100% passing the #8 sieve and 1% passing on the #200 sieve. This project was purposely selected so that the variation in material would be a minimum.

The test configurations were the same as those shown on Figure 8. A tabulation of the data shown on Table II shows that there is some variation when comparing individual results. However, in general, the averages are not significantly different whether the gage is next to or 3 feet away from the wall. The greatest difference occurred between the averages of A_4 and B_4. The difference was 2.2 pcf less when the source-detector rod axis was perpendicular to and the rod was about 10-3/4 inches from the wall.

CONCLUSION

The laboratory and field tests indicate that concrete walls do not significantly affect gage density measurements in structure backfill if the source-detector rod axis is kept parallel to and about 5 inches or more from the wall.

RECOMMENDATIONS

Based on the information in this report, it is recommended that all tests in structure backfill be made in the 8 inch direct transmission mode for both the Troxler and Portaprobe Gages. In addition, the source-detector rod axis should be approximately parallel and approximately 10 inches away from any structures and embankment walls. There should also be approximately 10" of clear area in front of the gage where the detector tube is located. A safety factor and gage configuration dictate a distance to wall which is somewhat greater than that indicated during the study.

This recommendation also appears to be satisfactory for the new source in the ground gages currently being manufactured by the gage industry. A few preliminary tests in the laboratory with the new gages seemed to confirm our other tests performed during this study.

NOTE

Although none of these tests were performed with a Troxler gage, the radiation principles involved in density measurements would hold approximately the same for both the Troxler and Portaprobe gages.

TABLE I

NUCLEAR GAGE DENSITY TESTS ON STRUCTURE

BACKFILL MATERIAL

Colton Interchange in District 08

Material - Sand with some Rock
Portaprobe Gage #32 used

All tests in 8" direct transmission mode and densities in pcf

Note: See Figure 8 for test configurations

DETECTOR ROD DISTANCE FROM WALL

	3"	6"		9"		12"	
Location	B_4	A_3	B_3	A_2	B_2	A_1	B_1
1	127.6	124.1	123.2	121.1	120.8	121.7	122.8
2	124.2	123.8	120.8	125.8	122.8	127.8	124.6
3	123.6	125.6	121.5	121.8	124.2	123.3	122.0
4	125.2	126.1	125.2	125.2	126.2	124.2	128.6
$\overline{X}$	125.2	124.9	122.7	123.5	123.5	124.3	124.5
Range	4.0	2.3	4.4	4.7	5.4	6.1	6.6

NUCLEAR GAGE DENSITY TESTS

ON STRUCTURE BACKFILL MATERIAL
Route 120 - Interstate 5 Interchange in District 10
Material - Sand 100% P#8 and 1% P#200
Portaprobe Gage #15
All tests in 8" Direct Transmission Mode and Densities in PCF

Note: See Figure 9 for test configurations

Side of Gage from Wall

	0		2"		4"		6"		8"		12"		24"		36"	
[illegible]	A_1	B_1	A_2	B_2	A_3	B_3	A_4	B_4	A_5	B_5	A_6	B_6	A_7	B_7	A_8	B_8
1	97.3	100.3	97.7	100.2	100.6	101.3	98.6	99.6	99.4	100.8	103.5	101.2	98.6	98.6	97.3	96.0
2	103.7	103.7	104.2	101.9	103.7	103.9	104.6	100.8	102.2	102.1	102.0	99.8	101.4	100.8	102.0	101.6
3	96.4	95.5	95.1	95.1	96.4	95.1	96.4	93.4	96.8	94.6	96.4	94.6	97.7	96.8	96.0	97.3
4	96.8	98.6	97.7	96.8	97.7	97.7	97.7	96.4	96.8	98.6	97.3	96.8				
5	101.4	97.7	97.3	96.8	98.2	96.8	99.8	97.3	97.3	99.1	98.6	97.7				
6	99.8	101.4	103.2	102.8	103.6	102.6	104.7	104.0	103.4	104.7	104.2	104.1				
7	95.9	97.3	96.8	96.4	97.3	96.4	97.3	92.6	97.3	95.5	95.5	94.2				
$\bar{X}$	98.8	99.2	98.9	98.6	99.6	99.1	99.9	97.7	99.0	99.3	99.6	98.3	99.2	98.7	98.4	98.3
Range	7.8	8.2	9.1	7.7	7.3	8.8	8.3	11.6	6.6	10.1	8.7	9.9	3.7	4.0	6.0	5.6

TABLE II

Figure 1

EFFECT OF RADIATION REBOUND
PORTAPROBE #15

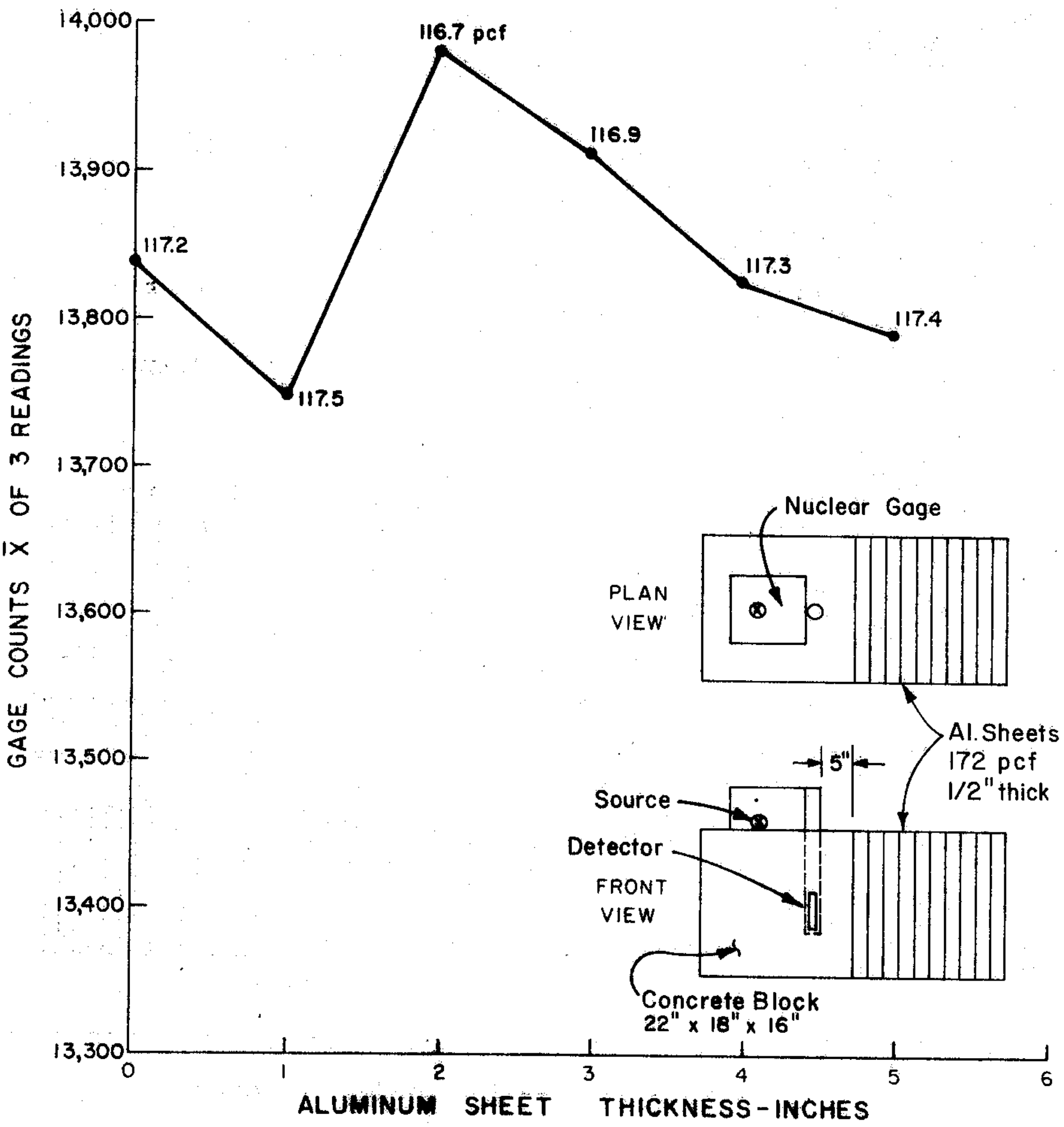

Figure 2

EFFECT OF RADIATION REBOUND
PORTAPROBE #15

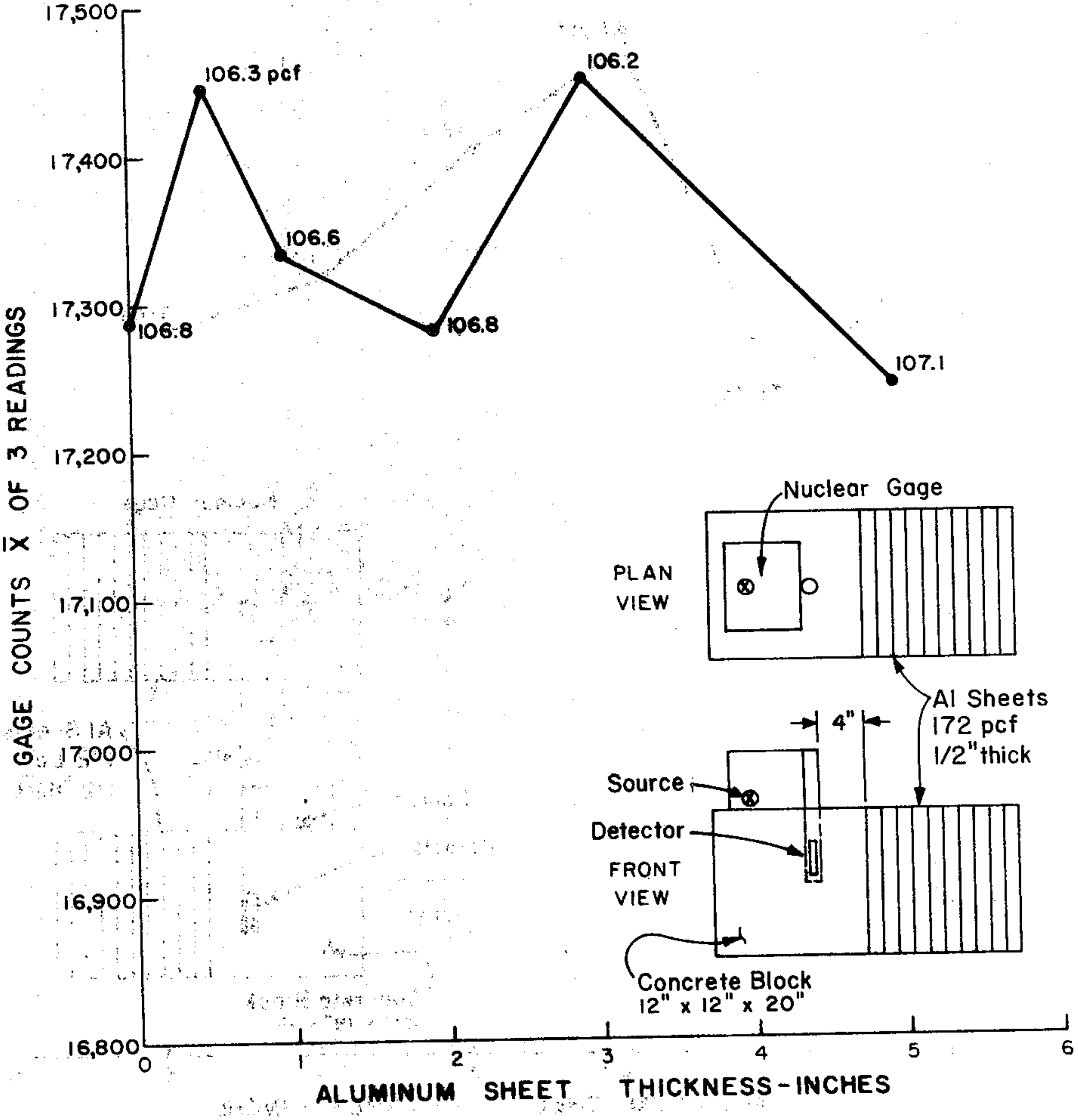

Figure 3

EFFECT OF RADIATION REBOUND
PORTAPROBE #15

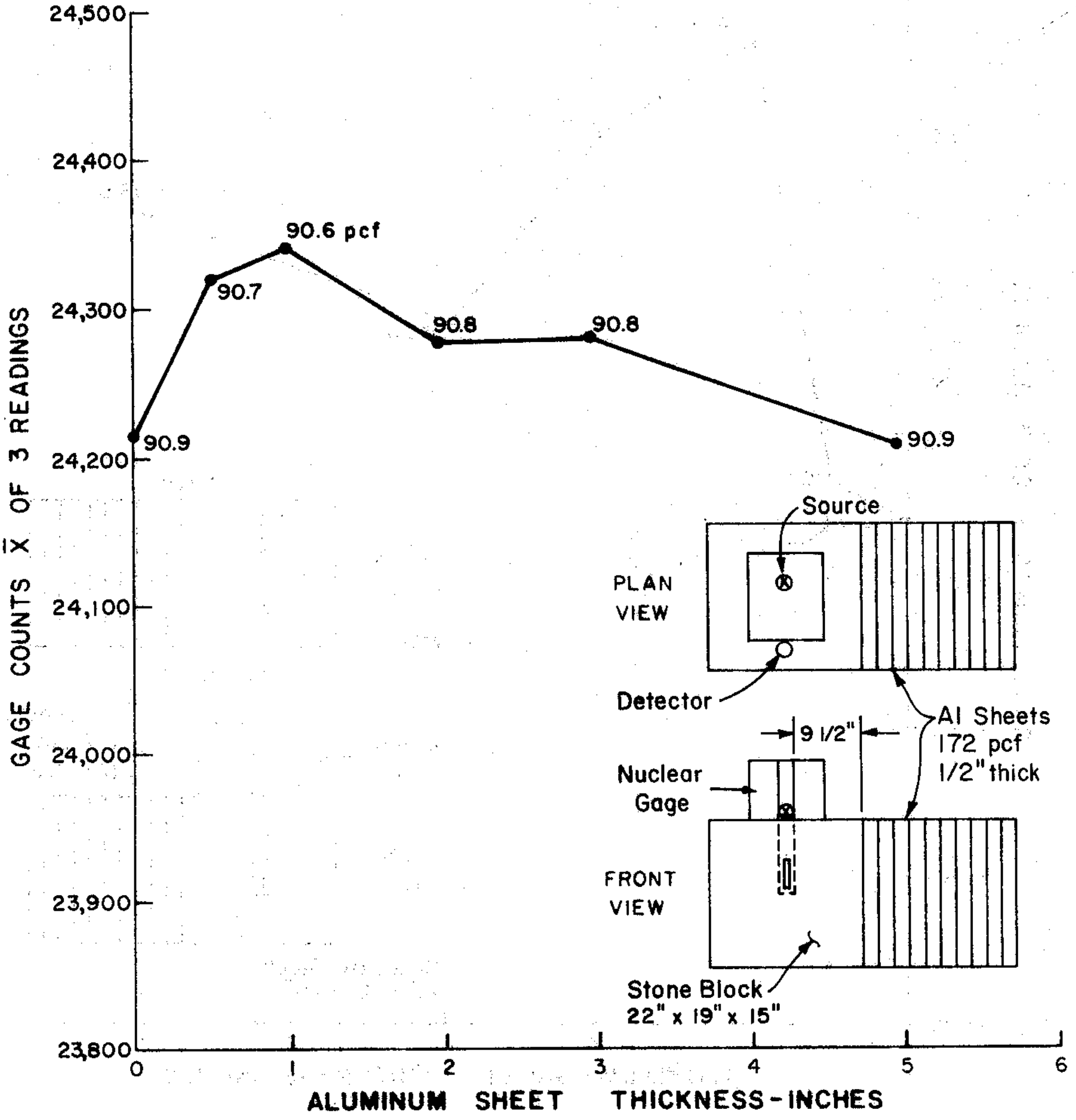

Figure 4

EFFECT OF RADIATION REBOUND
PORTAPROBE #15

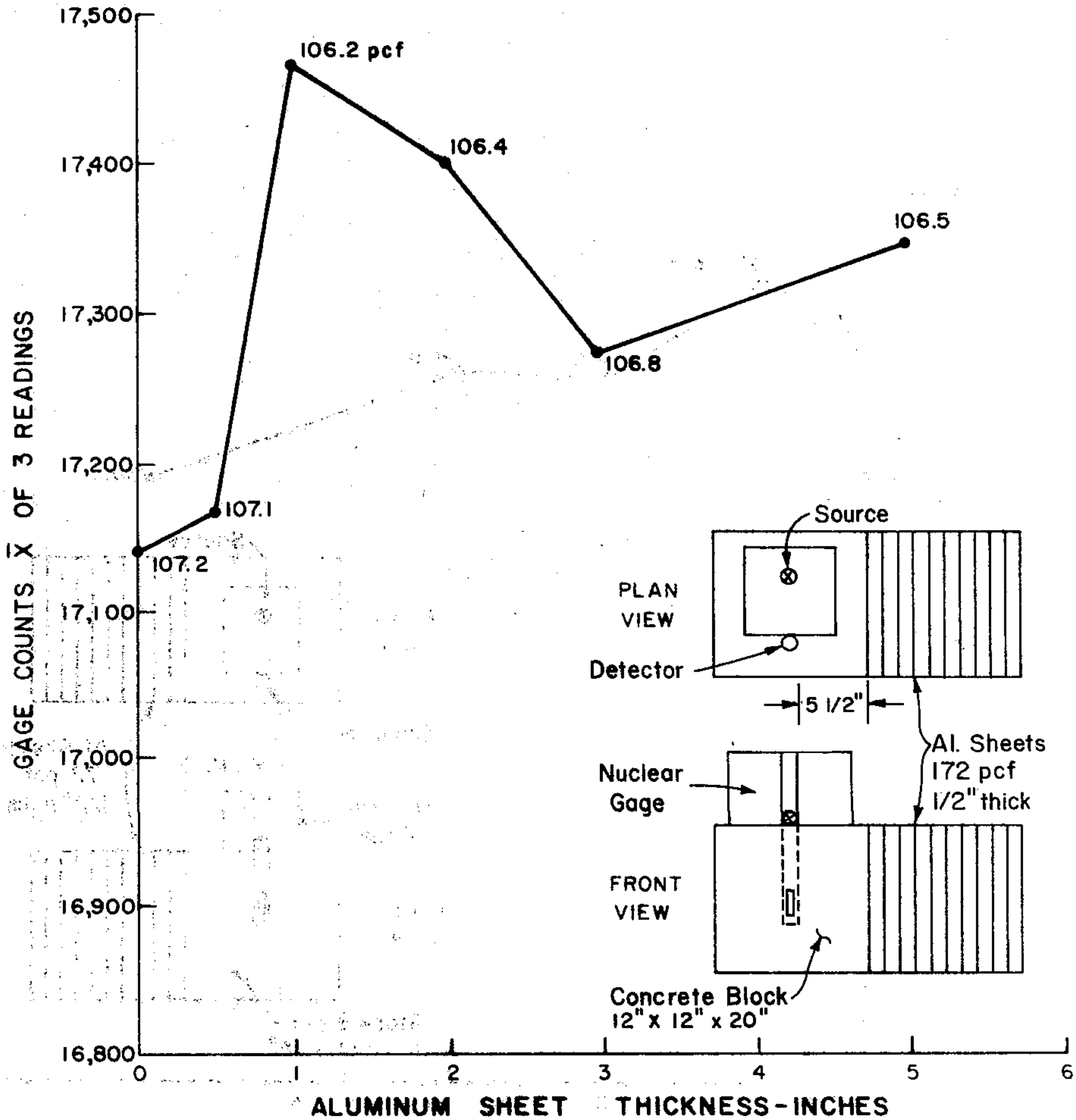

Figure 5

EFFECT OF RADIATION REBOUND
PORTAPROBE #15

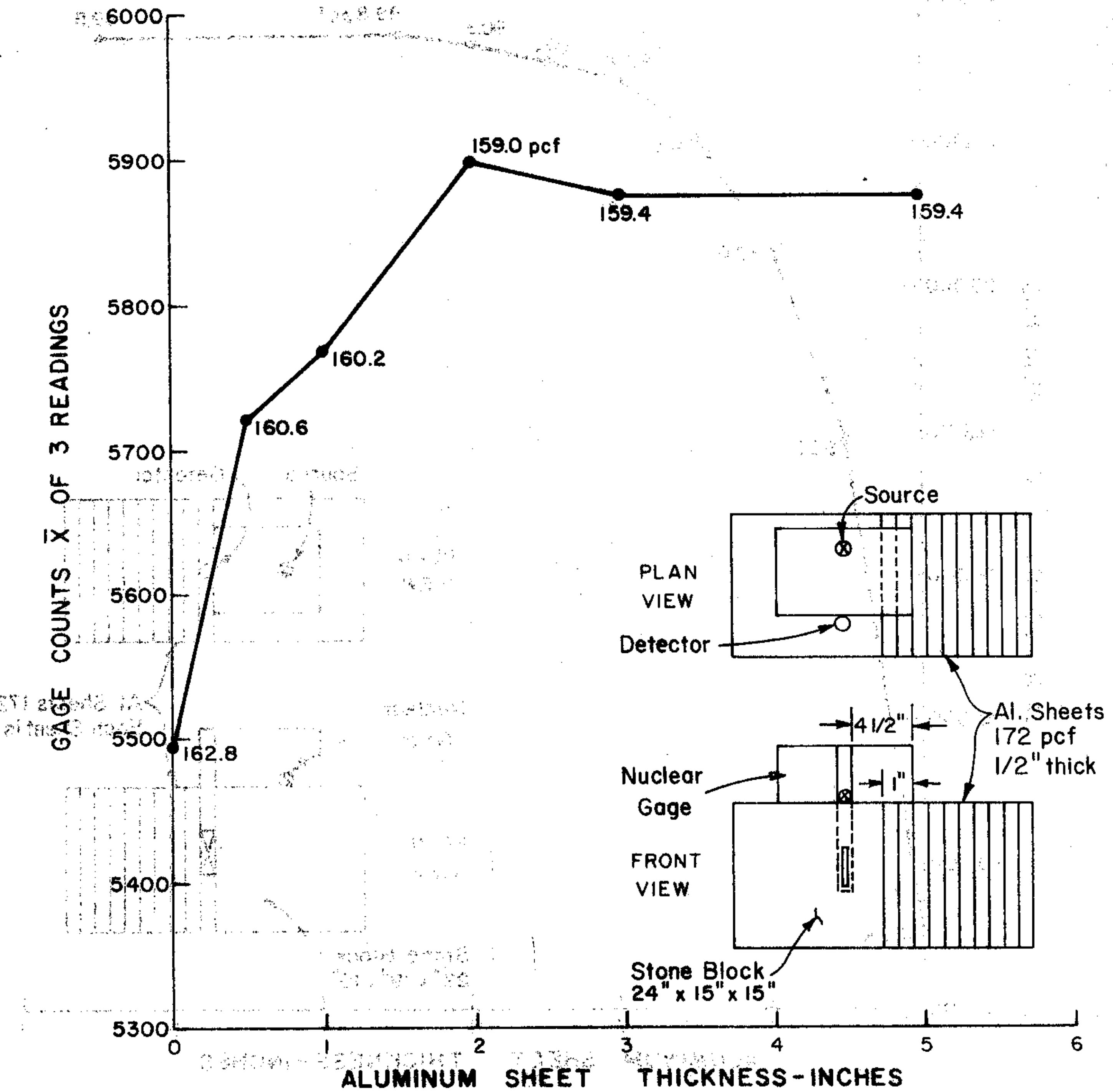

Figure 6

EFFECT OF RADIATION REBOUND
PORTAPROBE #15

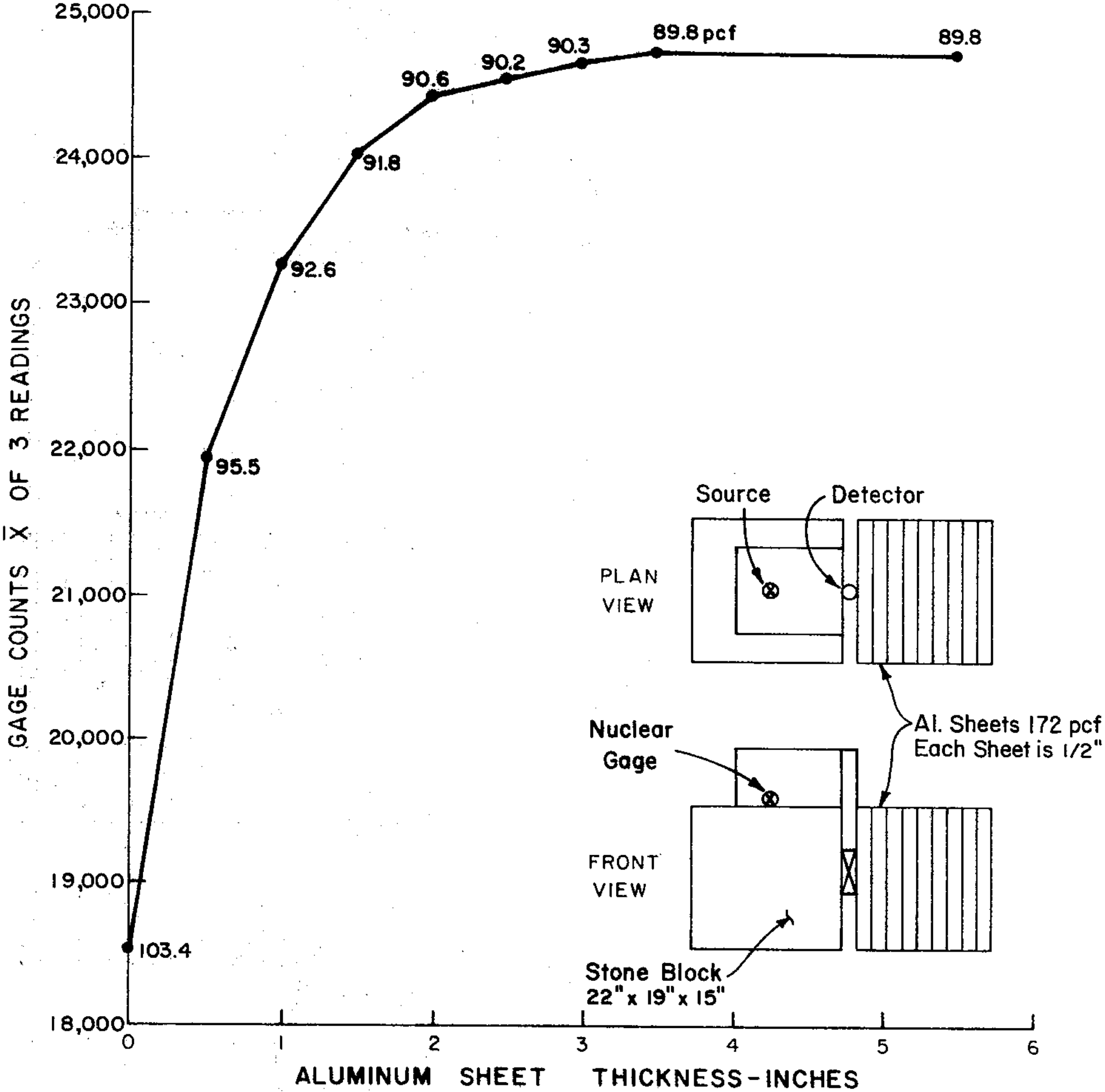

Figure 7

EFFECT OF RADIATION REBOUND
PORTAPROBE #15

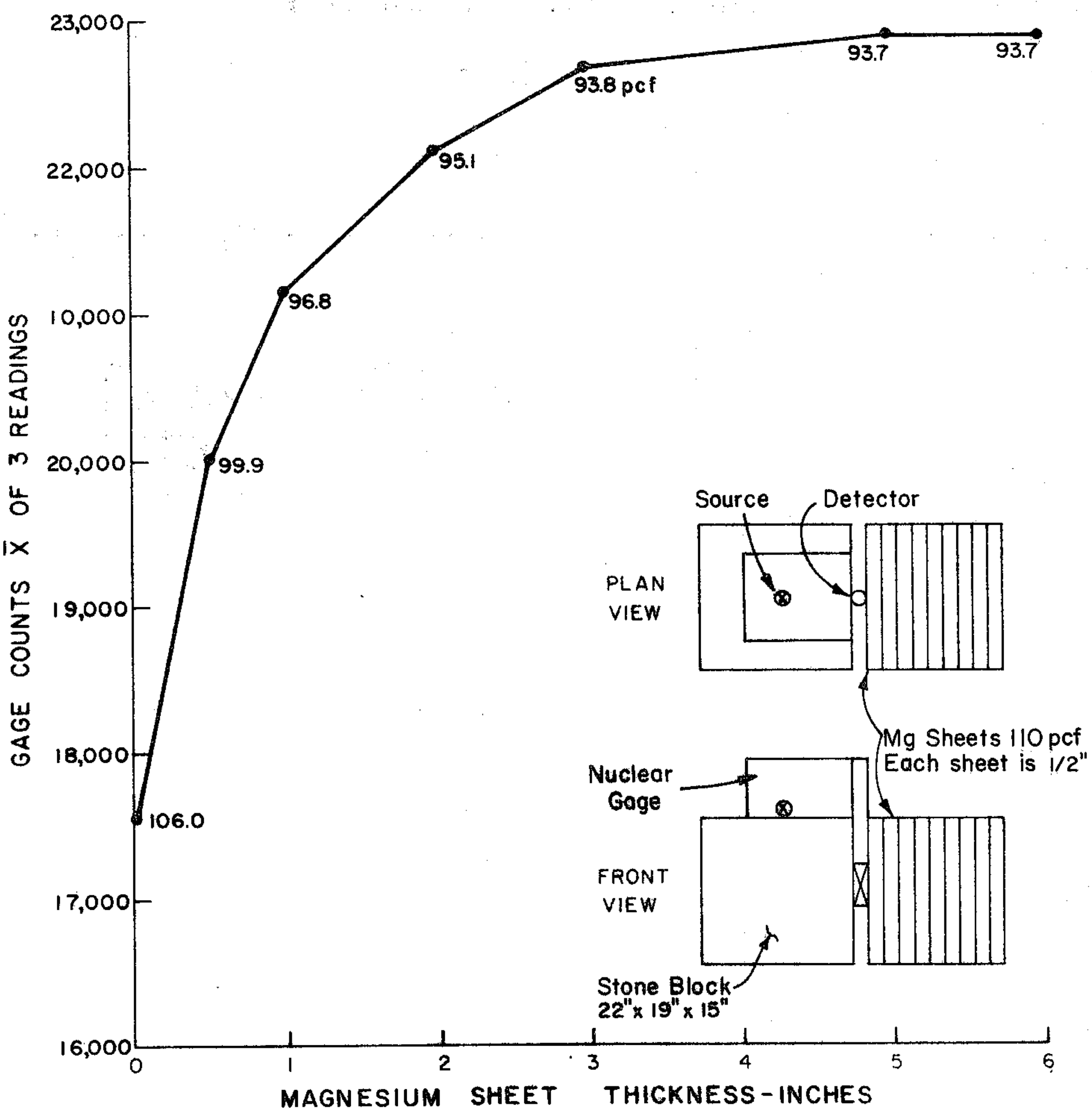

Figure 8

TEST CONFIGURATION ON STRUCTURE BACKFILL NEXT TO A CONCRETE WALL

COLTON INTERCHANGE IN DISTRICT 08

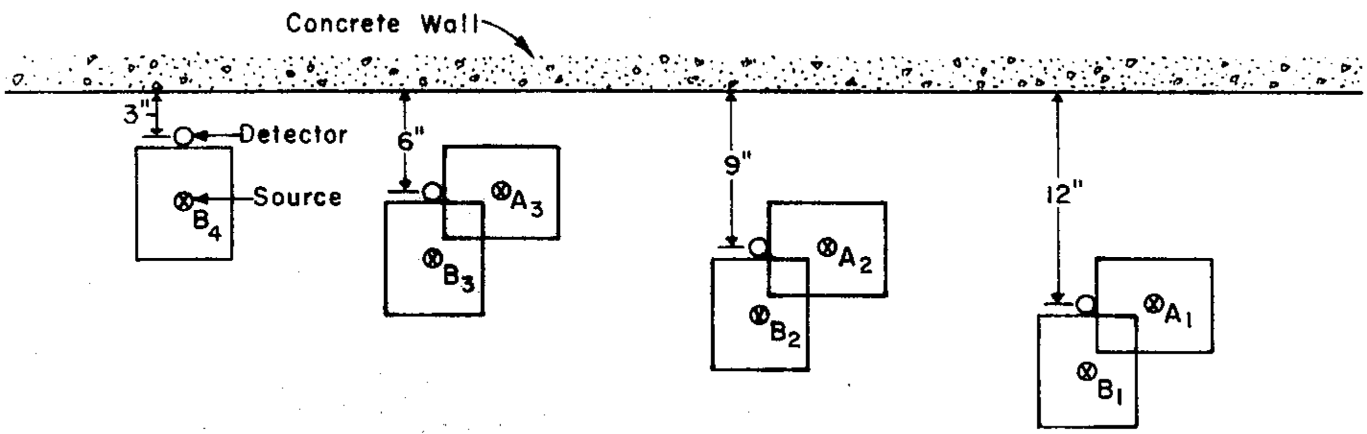

Figure 9

TEST CONFIGURATION ON STRUCTURE BACKFILL
NEXT TO A CONCRETE WALL

RTE 5-120 INTERCHANGE IN DISTRICT 10